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SPECIAL NOTICE

Owing to the necessity to conserve paper, under the present difficult conditions of supply, the contents of the Journal will, in future, be printed in smaller type.

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PROFESSOR THOMAS TURNER, M.Sc., A.R.S.M., F.R.I.C.

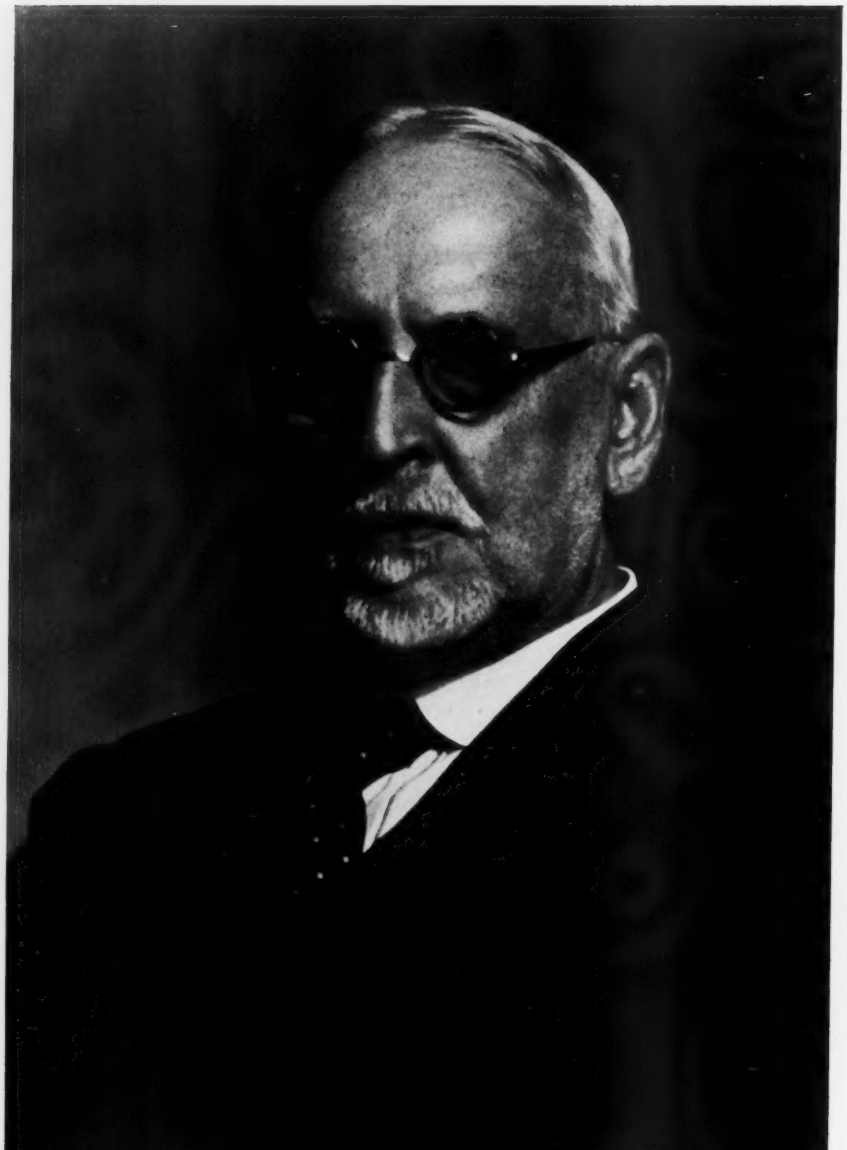
PROFESSOR THOMAS TURNER is one of the oldest living active members of The Iron and Steel Institute ; he was born at Birmingham in 1861. He was educated at a private school in Edgbaston and later at the Royal School of Mines, London. In 1883, he was appointed Demonstrator of Chemistry at Mason College, London, where he commenced his studies of the influence of silicon on the properties of iron and steel, and he was later promoted to Lecturer in Metallurgy. From 1894 to 1902 Mr. Turner held the position of Director of Technical Instruction to the Staffordshire County Council.

The next period of Professor Turner's career, which established his reputation throughout the country, was from 1902 to 1926 when he was Professor of Metallurgy at the University of Birmingham. In this position he was responsible for the design and equipment of the Metallurgical Department of the University as well as the technical training of many well-known metallurgists of the present day.

Professor Turner was elected a Member of The Iron and Steel Institute in 1887, became a member of Council in 1924, and was elected an Honorary Vice-President in 1931. He was awarded the Institute's highest honour, the Bessemer Gold Medal, in 1925, for his distinguished services in the advancement of the science of metallurgy of iron and steel. He has also been honoured by the awards of the Seaman Gold Medal of the American Foundrymen's Association, and the E. J. Fox Gold Medal of the Institute of British Foundrymen. He was further honoured, in 1921, by the establishment of a trust for the award of the Thomas Turner Gold and Bronze Medals, and prizes for metallurgy in the University of Birmingham.

In addition to his research work on the influence of silicon and other elements on iron and steel, the results of which have been largely applied in iron foundries throughout the world, Professor Turner has presented papers on the puddling of wrought iron, the reheating and rolling of finished iron, and on various aspects of the study of hardness. His expert knowledge has been widely recognised by numerous technical organisations and by the Government ; he has served on many committees, among them being the Advisory Committee of the Imperial Institute and the Councils of the British Cast Iron Research Association and the British Non-Ferrous Metal Research Association. He is an examiner in metallurgy to the Universities of London, Edinburgh, Glasgow, Manchester, Birmingham and Wales, and the Civil Service Commission and the City and Guilds Institute. He has also conducted enquiries for the Home Office and the Governments of Kashmir and Tasmania.

On his retirement from the University of Birmingham in 1926, he was given the title of Professor Emeritus. Since then he has acted as Consultant to Messrs. Fry's Metal Foundries and associated companies.



Professor Thomas Turner, M.Sc., A.R.S.M., F.R.I.C.
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IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Some Thermodynamical Aspects of the Formation of Inclusions in Mild-Steel Weld Metal

By E. C. Rollason, Ph.D., M.Sc., and E. Bishop, B.Sc. (Tech.)

SYNOPSIS

A method of thermodynamical analysis has been developed and applied to published analyses of non-metallic inclusions in mild-steel arc-weld deposits. In spite of the short times involved in arc welding, equilibrium of the molten metal is largely attained at an estimated temperature of about 1710° C., and the process of inclusion formation in weld metal has been shown to obey the general principles of thermodynamics.

Inclusions analysed at room temperature and also calculated to exist at the freezing point are plotted on a ternary (SiO_2–FeO–MnO) diagram from which can be deduced the change in inclusion composition during cooling from the freezing point. Evidence is given to indicate that the oxygen content of the weld metal is determined by the FeO content of the slag, as in large-scale steelmaking. Consequently a method has been evolved whereby the types and amounts of inclusions to be found in many weld metals can be determined by using the FeO content of the slag and the total manganese and silicon contents of the weld metal. Slags containing large quantities of CaF_2 are excepted.

INCREASING attention has recently been given to the constitution of mild-steel weld metal, especially as regards the type and amount of non-metallic inclusions it contains. A number of analyses of such inclusions have been published in recent years, by Sloman, Rooney, and Schofield,[1] Andrew,[2] and Reeve.[3] These data have been used in the present paper to form the basis of a thermodynamical analysis, with the object of obtaining a better understanding of the constitution of weld metal.

THERMODYNAMIC PRINCIPLES

If the activity of FeO in a slag is known, the equilibrium oxygen content of the metallic phase can be obtained at any temperature. The reaction

$$\text{FeO (in liquid slag)} \rightleftharpoons \text{Fe (liquid)} + \text{O (in liquid iron)}$$

in common with many other reactions of metallurgical importance, has been investigated experimentally, and the free-energy equation is known over a considerable temperature range. Thus, in the example quoted :

$$\log K = -\frac{6320}{T} + 2{\cdot}73$$

where $K = \dfrac{[\text{Fe}].[\text{O}]}{(\alpha\text{FeO})}$

and T is the temperature in ° Kelvin,
[Fe] = 1 for molten steel,
[O] = percentage by weight of oxygen dissolved in steel,
and (αFeO) = activity of FeO in slag, equal to the molar fraction.

The free-energy equations, from which the equilibrium constants can be calculated, are taken from a paper by Chipman.[4] The equations used in the present paper are tabulated in Appendix I.

In the case of pure molten iron, saturated with oxygen at, say, 2000° K., it is clear that on cooling iron oxide will separate out. Since in this case [Fe] = 1 and (αFeO) = 1 it can be stated that the amount of oxygen remaining in solution at any temperature T is given by :

$$\log [\text{O}] = -\frac{6320}{T} + 2{\cdot}73$$

If in addition the metal contains manganese, the inclusions will consist of a mixed Fe–Mn oxide. The two reactions will have equilibrium constants

$$\frac{[\text{Fe}][\text{O}]}{(\alpha\text{FeO})} \text{ and } \frac{[\text{Mn}][\text{O}]}{(\alpha\text{MnO})},$$

and the values of these constants at any given temperature are known. Moreover, it is known that

Oxygen in inclusions + oxygen in metal = total oxygen present,
Manganese in inclusions + manganese in metal = total manganese present,
and $\alpha\text{FeO} + \alpha\text{MnO} = 1$.

Manuscript received 16th October, 1947.
Dr. Rollason is Delegate Director and Head of the Research Department of Murex Welding Processes, Ltd., Waltham Cross.

Mr. Bishop was formerly employed in the Research Department of Murex Welding Processes, Ltd., and is now in the Research Department of Messrs. William Jessop and Sons, Ltd., Sheffield.

There are five relationships between the five unknowns (αFeO), (αMnO), total weight of inclusions, dissolved manganese, and dissolved oxygen. The solution of these equations will give all the unknowns at any temperature.

Molten weld metal, of course, contains many more materials, but theoretically a complete set of simultaneous equations can be found and solved to give the amount and composition of the inclusions. In practice the task is a very formidable one, owing to the large number of unknowns involved. As a first approximation, the four most important constituents, manganese, silicon, oxygen, and sulphur can be considered, in addition to the iron itself. There are ten simultaneous equations, found as follows:

Given that the total manganese, silicon, oxygen, and sulphur contents are known,

let dissolved	Mn	at equilibrium	$= A$ %	by weight of metal	
,, ,,	Si	,, ,,	$= B$,,	,, ,,	
,, ,,	S	,, ,,	$= C$,,	,, ,,	
,, ,,	O	,, ,,	$= D$,,	,, ,,	
,, MnO in inclusions		,, ,,	$= E$,,	,, ,,	$= E/71$ mols
,, SiO_2 ,,		,, ,,	$= F$,,	,, ,,	$= F/60$,,
,, FeO ,,		,, ,,	$= G$,,	,, ,,	$= G/72$,,
,, MnS ,,		,, ,,	$= H$,,	,, ,,	$= H/87$,,
,, FeS ,,		,, ,,	$= I$,,	,, ,,	$= I/88$,,

and let $\frac{E}{71} + \frac{F}{60} + \frac{G}{72} + \frac{H}{87} + \frac{I}{88} = K_m$ .....(1)

Then the activity of MnO in the inclusion phase

= the molar fraction of MnO

$$= \frac{E}{71} \times \frac{1}{K_m}, \text{ or } \frac{E}{71K_m}.$$

Now, the equilibrium constant for this reaction is

$$\frac{[\text{Mn}][\text{O}]}{(\alpha\text{MnO})} = \frac{A \times D \times 71K_m}{E}$$

and its value is known at any temperature.

Five expressions of this type are obtained for the three oxides, MnO, FeO, and SiO_2, and for the two sulphides, FeS and MnS.

A further set of four relationships is given by the material balances for manganese, silicon, oxygen, and sulphur. Thus, for example,

Mn in metal + Mn as sulphide + Mn as oxide = total Mn,

$$\text{or } A + \frac{55}{87}H + \frac{55}{71}E = \text{total Mn}.$$

The tenth expression, involving K_m, is given in equation (1):

$$K_m = \text{(mols in inclusions)}.$$

This expression is merely introduced as a convenience, to shorten the equilibrium constants. It has been assumed that the activities of the various components of the inclusions are equal to the molar fraction present, according to Raoult's Law.

It has been found to be impracticable to solve these ten simultaneous equations by the normal algebraic method of elimination, as the final equation contains higher powers of the last remaining variable. A fairly rapid trial and error method of solution developed by Bishop has, however, been found to be suitable. A brief description of the method is given in Appendix II.

This group of equations takes no account of phosphorus, titanium, chromium, and aluminium, although these figure in most inclusion analyses. Each additional element to be considered adds two unknowns to the list, and increases the difficulty of obtaining a solution. However, with the exception of titanium oxide in some inclusions, the oxides of these elements are present in negligible amounts.

In the next section of the paper the ten equations are applied to weld metals of known manganese, silicon, sulphur, and oxygen contents in order to calculate the amounts of inclusions present; the results are compared with actual inclusion analyses. The assumption is made that the inclusions maintain equilibrium composition throughout the cooling cycle of the weld metal, down to its solidification point.

THE FORMATION OF INCLUSIONS IN COOLING WELD METAL

The most recently published analyses of inclusions in weld metal are those of Sloman, Rooney, and Schofield. Two systems (those for the 12-S.W.G. electrodes *B* and *C*) were chosen from their table of results for complete solution at temperatures of 1900, 1850, 1800, and 1750° K., according to the relationships obtained in the preceding section. The results of the calculations are given in Tables I and III.

It is noteworthy that no less than 0·045% of oxygen remains soluble at temperatures as low as

Table I

CALCULATED VALUES OF VARIOUS ELEMENTS AND INCLUSIONS IN MOLTEN METAL *B* AT FOUR TEMPERATURES

Weld Metal *B*, from a 12-gauge iron–manganese silicate type electrode, had the following analysis: Mn, 0·40%; Si, 0·040%; S, 0·030%; and O, 0·14%

Temperature:	1900° K.	1850° K.	1800° K.	1750° K.
Dissolved Mn, %	0·370	0·349	0·322	0·290
,, Si, %	0·022	0·015	0·010	0·007
,, S, %	0·029	0·028	0·027	0·026
,, O, %	0·098	0·078	0·060	0·045
MnO, wt.-%	$0·039_2$	0·066	0·101	0·140
SiO_2, wt.-%	$0·038_5$	0·054	0·064	0·071
FeO, wt.-%	$0·055_2$	0·081	0·102	0·114
MnS and FeS		negligible		
Inclusion analysis:				
MnO, wt.-%	29·5	32·9	37·8	43·1
FeO, wt.-%	41·5	40·3	38·1	35·1
SiO_2, wt.-%	29·0	26·7	24·2	21·8

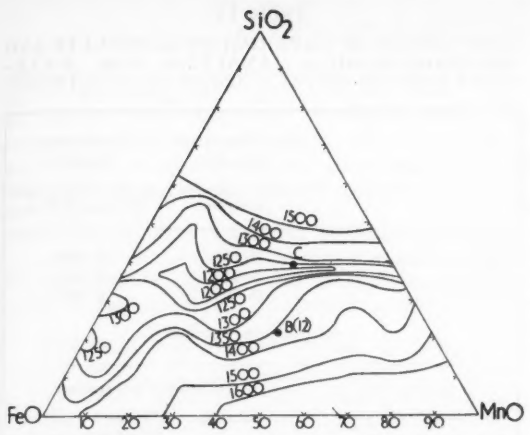

Fig. 1—Liquidus surface of system FeO–MnO–SiO_2, showing the calculated compositions at 1750° K. of inclusions in *C* and *B* (12 S.W.G.) weld metal

1750° K., which is about the freezing point of the metal. On freezing this oxygen must separate out, giving additional inclusions. Thus the weld metal contains two forms of inclusion, namely:

(1) Inclusions made up of about two-thirds of the total oxygen and a very small amount of sulphur, with the necessary iron, manganese, and silicon. These are formed while the metal is still molten, and are therefore free to coalesce together into inclusions of relatively large size.

(2) Inclusions formed during or after solidification of the metal, which are likely to be very small and finely dispersed throughout the matrix.

If the phase diagram for the system FeO–MnO–SiO_2, according to W. R. Maddocks,[5] (Fig. 1), is examined, the freezing point of the mixture containing 43% of MnO, 35% of FeO, and 22% of SiO_2 is found to be about 1370° C., or 1640° K. The first type of inclusion will still be liquid when the metal freezes, and will therefore be seen in the form of spherical droplets.

Now, the weld metal at freezing point contains, according to calculations, 0·045% of oxygen, and almost all its sulphur. Besides iron, there is only 0·290% of manganese to combine with this oxygen and sulphur. Silicon has been reduced to a trace, and there are only traces of other materials present. The oxide–sulphide system has not been investigated a great deal, but has been discussed as a "reciprocal salt pair" by Benedicks and Löfquist.[6] From the diagram they give it can be deduced that for an oxygen-to-sulphur ratio of about 3 : 2, as in the present case, about 25% of the iron in an FeO–FeS mixture can be replaced by manganese without either MnO or MnS separating out. There is thus no tendency for manganese sulphide to form during solidification and iron sulphide is known to be appreciably soluble in mild steel. The second form of inclusion must therefore be mainly iron oxide. It is unfortunate that the course of reactions in the solid metal cannot be studied more closely than this, owing to the absence of the necessary thermodynamic data.

Summing up the results of this thermodynamic analysis it can be stated that, provided the metal remains in equilibrium during the cooling cycle, it should be found to contain:

(1) Discrete particles of iron–manganese silicate. Figure 1 indicates that these will crystallize as fayalite containing manganese oxide, *i.e.*, $2Fe(Mn)O.SiO_2$.

(2) Iron oxide in fine dispersion, also containing some MnO in solid solution.

(3) Sulphur still largely in solution in the steel.

Sloman and co-workers carried out analytical and X-ray crystallographic tests on the alcoholic iodine residues from weld metal *B*. The theoretical and experimental results are compared in Table II.

In a comparison of the experimental and calculated analyses, the following points are evident:

(1) The calculated SiO_2 figure is too high. Zappfe and Sims[7] have thrown doubt on the commonly used thermodynamic data for the Si–O equilibrium in molten iron; according to them silicon is more soluble in steel than the $Si \rightarrow SiO_2$ reaction data would indicate, owing to the formation of SiO.

(2) The MnO figures are in fair agreement. A little MnO may form during solidification.

(3) The difference between the FeO figures indicates the formation of FeO during solidification.

Sulphur is omitted from Table III and all subsequent calculations as it became apparent that it remains almost completely soluble down to the solidification temperature of the metal. This omission considerably eases the work of solving the equations.

According to Fig. 1, the inclusion composition at 1750° K., taken from Table III, has a liquidus temperature of about 1200° C., or 1470° K., which is 170° K. lower than in the case of weld metal *B*. From the isotherms it can be deduced that the material first crystallizing out is rhodonite, $MnO.SiO_2$.

In comparison with the previous example, the weld metal at the freezing point contains much less oxygen, and much more manganese and silicon. It is therefore

Table II

COMPARISON OF EXPERIMENTAL RESULTS AND THERMODYNAMICAL ANALYSIS FOR INCLUSIONS IN WELD METAL *B* (12-GAUGE ELECTRODE)

	Experimental Results	Calculated Results
	Total Inclusion Analysis	Inclusions in Liquid Metal at 1750° K.
MnO, wt.-% ...	0·162	0·140
FeO, ,, ...	0·200	0·114
SiO_2, ,, ...	0·044	0·071

Compounds Present

X-Ray Data		Theoretical Deductions	
Fayalite ...	Present	Fayalite ...	Formed above melting point
Wüstite ...	Present	Wüstite ...	Formed on freezing
Sulphides ...	Absent*	Sulphides ...	No tendency to form

* Chemical tests revealed the presence of sulphide in the residue but the amount was not stated.

Table III

CALCULATED VALUES OF VARIOUS ELEMENTS AND INCLUSIONS IN MOLTEN WELD METAL *C* AT FOUR TEMPERATURES

Weld metal *C*, from a 12-gauge fluid-rutile type of electrode, had the following analysis: Mn, 0·47%; Si, 0·060%; S, 0·033%; and O, 0·090%

Temperature :	1900° K.	1850° K.	1800° K.	1750° K.
Dissolved Mn, %	0·460	0·447	0·432	0·419
,, Si, %	0·051	0·042	0·034	0·028
,, O, %	0·074	0·056	0·041	0·029
MnO, wt.-%	$0·013_2$	$0·029_6$	$0·048_9$	$0·065_9$
SiO_2, ,,	$0·018_4$	$0·038_5$	$0·055_7$	$0·069_3$
FeO, ,,	$0·015_0$	$0·028_3$	$0·037_5$	$0·041_4$
Inclusion analysis:				
MnO, wt.-%	28·3	30·7	34·4	37·4
FeO, ,,	32·2	29·3	26·4	23·4
SiO_2, ,, ...	39·5	40·3	39·2	39·2

Table IV

COMPARISON OF EXPERIMENTAL RESULTS AND THERMODYNAMICAL ANALYSIS FOR INCLUSIONS IN WELD METAL *C* (12-GAUGE ELECTRODE)

	Experimental Results	Calculated Results
	Total Inclusion Analysis	Inclusions in Liquid Metal at 1750° K.
MnO, wt.-% ...	0·115	0·066
FeO, ,, ...	0·011	0·041
SiO_2, ,, ...	0·099	0·069
Compounds Present		
X-Ray Data	Theoretical Deductions	
Rhodonite	Rhodonite ...	Formed above melting point
Manganese sulphide	Rhodonite ...	Formed on solidification
	MnS ...	Formed on solidification

Table V

EXPERIMENTAL AND CALCULATED DATA FOR SEVEN WELD METALS

Weld-Metal Type:	*A*	*B* (12 S.W.G.)	*B* (8 S.W.G.)	*C*	*D*	*E*	*F*
		Fe-Mn Silicate		Fluid Rutile			
Element Dissolved in Weld at 1750° K., Calculated :							
Mn, wt.-%	0·409	0·290	0·174	0·419	0·189	0·184	0·477
Si, wt.-%	0·022	0·008	0·002	0·028	0·015	0·007	0·084
O, wt.-%	0·031	0·045	0·066	0·029	0·041	0·049	0·019
Oxide in Weld at 1750° K., Calculated :							
I MnO, wt.-%	0·079	0·140	0·085	0·066	0·053	0·073	0·030
I FeO, wt.-%	0·051	0·114	0·129	0·041	0·073	0·104	0·012
I SiO_2, wt.-%	0·074	0·071	0·038	0·069	0·096	0·077	0·056
Inclusion Analysis Calculated from I :							
MnO, wt.-%	38·7	43·1	33·8	37·4	23·8	28·7	30·7
FeO, wt.-%	24·9	35·1	51·1	23·4	33·0	41·0	11·8
SiO_2, wt.-%	36·4	21·8	15·2	39·2	43·2	30·3	57·5
Iodine-Residue Analysis:							
II MnO, wt.-%	0·123	0·162	0·145	0·115	0·158	0·177	0·091
II FeO, wt.-%	0·016	0·200	0·192	0·011	0·023	0·179	0·004
II SiO_2, wt.-%	0·099	0·044	0·041	0·099	0·122	0·077	0·061
II − I—Separates on Solidification:							
MnO, wt.-%	0·044	0·022	0·060	0·049	0·105	0·104	0·061
FeO, wt.-%	− ve	0·086	0·063	− ve	− ve	0·075	− ve
SiO_2, wt.-%	0·025	− ve	...	0·030	0·026	...	0·005
Inclusion Composition from Iodine-Residue Analysis :							
MnO, wt.-%	51·6	39·9	38·3	51·1	52·1	40·9	58·3
FeO, wt.-%	6·8	49·2	50·8	4·9	7·6	41·3	2·6
SiO_2, wt.-%	41·6	10·8	10·9	44·0	40·3	17·8	39·1
X-Ray Analysis of Iodine Residue	rhodonite and MnS	fayalite and FeO	fayalite and FeO	rhodonite and MnS	rhodonite and MnS	fayalite and FeO	rhodonite and MnS

to be expected that on solidification the oxygen will combine preferably with manganese and silicon, and the sulphur with manganese, to form additional rhodonite and MnS. In Table IV the experimental results obtained by Sloman and co-workers on this weld metal are compared with the calculated results from Table III.

Again, quite good agreement is obtained, except that in this case the FeO calculation is too high. The difference between the MnO and SiO_2 figures indicates that these two oxides form in the solid metal.

RESULTS FOR OTHER WELD METALS

The results so far given indicate that, in spite of the short time available for the cooling and solidification, the chemical reactions nevertheless maintain equilibrium conditions fairly closely. While it is interesting to study the course of the formation of inclusions from 2000° K. to solidification, it is clear that the important results are those at solidification point, taken to be 1750° K. The composition of the slag phase at this temperature determines the main type of inclusion, while the relative proportions of manganese, silicon, sulphur, and oxygen still in solution determine the type of inclusions formed in the solid metal.

For confirmation, therefore, the remaining weld metals studied by Sloman and co-workers have been examined, at the single temperature of 1750° K. Sulphur has been assumed to remain completely soluble. The collected results are given in Table V and compared with the iodine-residue analyses.

It can be seen that the calculated inclusion analyses fall into two groups, corresponding to the two inclusion types identified by X-ray crystallography. There is usually some error in either the calculated FeO or the SiO_2, showing that the inclusions do not exactly maintain equilibrium. In general, however, the agreement between theoretical and experimental results is good.

On the ternary diagram, Fig. 2, are plotted inclusion compositions calculated to exist at freezing point in the liquid metal. The experimentally determined inclusion analyses, which are also plotted, are made up from inclusions formed in the liquid metal and in the solid metal. The direction of the line from the calculated to the experimental composition indicates the change in inclusion analysis occurring during solidification and cooling from the freezing point.

The case of weld metal *F* is interesting. As Fig. 2 shows, the composition calculated for the inclusions at 1750° K. is within the immiscibility range, and if it were actually formed, pure solid silica would separate out. The activity of the SiO_2 in such a mixture is therefore very much higher than is indicated by the molar fraction of SiO_2 in the mixture. In other words, the calculated inclusion composition for weld metal *F* is one which it is quite impossible to attain in practice. The first appearance of a pure SiO_2 phase during the cooling of the system would inhibit the formation of any more SiO_2.

By reference to Figs. 1 and 2, noting particularly the position of the lowest isotherm, 1200° C., it can now be stated that the SiO_2 content of the equilibrium inclusion composition at 1750° K. is the main factor

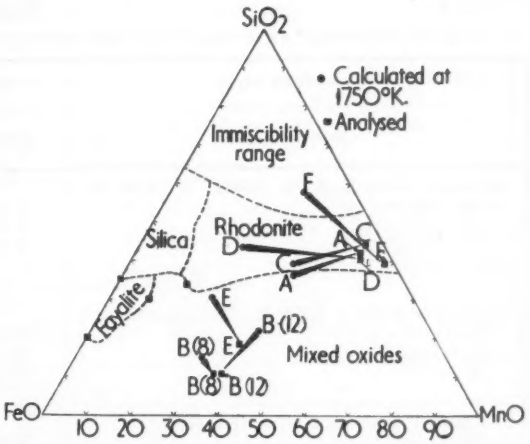

Fig. 2—Primary crystallization fields in the system FeO–MnO–SiO_2, showing the calculated and experimentally determined compositions of inclusions

which determines the type of inclusion which forms. Below about 30% SiO_2, the primary phase is Fe(Mn)O, and above 30% SiO_2, $MnO.SiO_2$. The removal of Fe(Mn)O by crystallization leaves a liquid composition which tends towards $2Fe(Mn)O.SiO_2$, so that the latter material also appears. The removal of $MnO.SiO_2$, on the other hand, does not alter the composition of the remaining liquid, so that this is the only crystalline phase which appears.

Since MnS is immiscible with silicate, it can form a separate phase. It can therefore be identified in conjunction with rhodonite-type inclusions. In cases where the manganese content is too low for manganese sulphide formation, much of the sulphur remains dissolved in the steel matrix. This is in agreement with Whiteley's finding,[8] and explains why, in the "fayalite type" weld metal, sulphides are more difficult to identify.

Finally, while the absence of thermodynamic data makes it impossible to study the course of reactions in the solid metal very closely, one more deduction can be made. Where only FeO is separating out in the solid steel, the process is probably slow and extends over a range of several hundred degrees below the freezing point. MnO and SiO_2, on the other hand, are relatively much less soluble in solid steel than they are in liquid steel. In consequence, FeO formed after solidification will be much more finely dispersed than $MnO.SiO_2$ formed in the same conditions.

A THIRD INCLUSION TYPE

Table VI gives the calculated and experimental data for inclusions in five weld metals of the high-manganese type. Of these, *B*16, *B*19, and *AW*2 are made from electrodes of the hydrogen-controlled ferritic type, and the remaining two are self-explanatory.

Data concerning the first three weld metals are taken from an unpublished report No. 1318 by the Welding and Gas Cutting Branch of the Fighting Vehicles Design Department, Ministry of Supply. It was stated that tephroite was present in the two

Table VI

EXPERIMENTAL AND CALCULATED DATA FOR FIVE HIGH-MANGANESE WELD METALS

Weld-Metal Type:	*B*16	*B*19	*AW*2	Fluorite Base	Unionmelt
Electrode Coating:	Fluoride Hydrogen-Controlled Ferritic			Automatic	Submerged Arc
Element Dissolved in Weld at 1750° K., Calculated:					
Mn, wt.-%	1·313	2·023	1·823	0·783	1·006
Si, wt.-%	0·041	0·075	0·269	0·316	0·359
O, wt.-%	0·017	0·012	0·009	0·011	0·010
Oxides in Weld at 1750° K., Calculated:					
I MnO, wt.-%	0·125	0·100	0·032	0·022	0·057
I FeO, wt.-%	0·025	0·013	0·005	0·007	0·015
I SiO_2, wt.-%	0·036	0·024	0·024	0·051	0·109
Inclusion Analysis Calculated from I.					
MnO, wt.-%	67·2	73·0	52·4	27·5	31·5
FeO, wt.-%	13·4	9·5	8·2	8·7	8·3
SiO_2, wt.-%	19·4	17·5	39·4	63·8	60·2
Iodine-Residue Analysis:					
II MnO, wt.-%	0·044	0·031	0·050	0·048	0·098
II FeO, wt.-%	0·004	0·006	0·005	0·004	0·005
II SiO_2, wt.-%	0·025	0·016	0·024	0·042	0·115
II − I—Separates on Solidification:					
MnO, wt.-%	?	?	0·028	0·026	0·041
FeO, wt.-%	?	?	...	...	...
SiO_2, wt.-%	?	?	...	...	0·006

B metals, and it was found that the total oxygen values obtained by the alcoholic-iodine method were much lower than those obtained by the vacuum-fusion method. It was considered that some of the oxide inclusions (possibly MnO or (MnFe)O) were in a finely divided condition and were dissolved in the iodine solution. The calculated inclusion analyses for *B*16 and *B*19 show that a silicate of the tephroite type ($2MnO.SiO_2$) should be formed, with an excess of free MnO. The other three metals, *AW*2, Unionmelt, and fluorite base,[1] all contain the normal rhodonite-type inclusions, but owing to the large excess of manganese present, the inclusions forming in the solid metal are mainly MnO, with little or no SiO_2.

TYPES OF INCLUSIONS

It is interesting to note that the high-silica inclusion is always a manganese silicate, containing relatively little iron, whereas the low-silica inclusion is an iron silicate and mixed iron–manganese oxide. An explanation is possible in the light of the FeO–MnO–SiO_2 diagram, Fig. 1.

The ternary eutectic point on the FeO–MnO–SiO_2 diagram is at the composition 16% MnO, 50% FeO, 34% SiO_2. All compositions containing less SiO_2 must precipitate mixed MnO–FeO primary crystals, and all compositions containing more MnO must precipitate $MnO.SiO_2$ primary crystals. The compound $2MnO.SiO_2$ is only formed by a peritectic reaction, which is unlikely to take place, except in the presence of much free MnO.

In the iodine-residue analyses of Table V, MnO varies from 0·9% to 0·18%, and SiO_2 from 0·04% to 0·12%, whereas FeO varies from 0·004% to 0·200%. Thus, while the MnO and SiO_2 remain relatively constant, the FeO varies much more widely. When the total silicon is low, and the total oxygen high, the extra oxygen is taken up very largely by iron, although the MnO itself may have increased somewhat. Only in high-manganese weld metal is it possible to obtain MnO inclusions, as shown in Table VI.

RELATIONSHIP BETWEEN METAL ANALYSIS AND INCLUSION CONTENT

The agreement between experimental data and the results of thermodynamical calculation and deduction is sufficiently close to indicate that, despite the rapid cooling which weld metal undergoes, equilibrium conditions are nevertheless maintained. Thus, the types of inclusion which will be found in weld metal are determined by the manganese, silicon, and oxygen contents of the metal.

In Tables I and III, the formation of inclusions is studied as the weld-metal temperature falls. It appears that at some stage in the process, all the manganese, silicon, and oxygen was dissolved in the weld metal. This weld metal was produced by reaction with a slag, and if this reaction reaches equilibrium, it is clear that the oxygen content of the weld metal is fixed by the FeO content of the slag, exactly as in steelmaking by the normal methods.

In order to determine whether equilibrium was

Table VII

ANALYSES AND EQUILIBRIUM TEMPERATURES FOR TEN SIMPLE MILD-STEEL ELECTRODES

Electrode Number:	1	2	3	4	5	6	7	8	9	10
Slag Analysis:										
FeO, wt.-%	19·1	20·5	22·0	22·3	21·2	19·4	20·7	22·7	18·0	20·9
SiO_2, wt.-%	43·5	44·2	45·0	44·0	43·6	42·4	44·3	41·1	42·4	41·9
Total silicon in weld metal, %	0·216	0·246	0·274	0·22	0·18	0·21	0·32	0·24	0·22	0·28
Equilibrium constant*	1·43	1·82	2·29	1·95	1·46	2·23	1·58	2·33	1·30	2·38
Equilibrium temperature, ° K.	1950	1980	2010	1990	1950	2010	1960	2020	1940	2020

* Equilibrium constant $= \frac{[Si](\alpha FeO)^2}{(\alpha SiO_2)} \times 10^{-5}$

reached between slag and weld metal, and if so, what the reaction temperature normally is, the authors carried out some experimental tests. A number of simple electrodes of various compositions were made, and the slag and metal were collected and analysed for FeO and SiO_2 and for silicon respectively. The analytical data, the equilibrium constant, $\frac{[Si]\,(\alpha FeO)^2}{(\alpha SiO_2)}$ and the corresponding equilibrium temperature, are all included in Table VII.

The equilibrium temperatures give an average of 1983° K., with a standard deviation of $\pm$ 30°. The reaction studied is :

2FeO (in slag) + Si (in weld metal) $\rightleftharpoons$ 2Fe (weld metal) + SiO_2 (in slag).

Since this reaction reaches equilibrium, it is clear that by analysing the welding slag for FeO, the oxygen content of the weld metal can be ascertained without making a complete inclusion analysis.

It must be pointed out that in the equilibrium constant the terms used are the activities of the reacting oxides. In simple silicate or silicotitanate slags these are approximately equal to the molar fraction of the oxide in the slag. This is not the case with slags rich in CaO or CaF_2. Until much more is known of the constitution of such slags, they must be omitted from consideration.

CONCLUSION

The process of inclusion formation in weld metal has been shown to obey the general principles of thermodynamics. In proving this point, a method has been evolved whereby an estimate of the types and amounts of inclusions to be found in a given weld metal can be obtained very simply, using only the FeO content of the slag and the total manganese and silicon contents of the weld metal. The necessity for complicated and laborious inclusion analyses is thereby obviated.

Briefly, the method of estimating inclusion analyses is as follows :

(1) Analyse the slag for total iron oxide. The FeO fraction by weight can be used if desired, but it will be more accurate to use the molar fraction, calculated from a complete slag analysis.

(2) Analyse the weld metal for total manganese and silicon.

(3) From the FeO figure, calculate the total oxygen. Since

$$\log \frac{[O]}{(\alpha FeO)} = -\frac{6320}{T} + 2{\cdot}73$$

and the equilibrium temperature is roughly 1980° K.

$$\therefore \log [O] = \log (\alpha FeO) - 0{\cdot}44$$

(4) Since total manganese, silicon, and oxygen figures are available, the equilibrium composition of the inclusions at 1750° K. can be found by the method described. The position of this FeO–MnO–SiO_2 composition on the equilibrium diagram will then facilitate an estimation of the final inclusion content.

Acknowledgments

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APPENDIX I

Free-Energy Data on Metallurgical Reactions*

Equilibrium constants are obtained from the free-energy change $\Delta F°$, accompanying a reaction, according to the relationship :

$$\log_{10} K = -\frac{\Delta F°}{4{\cdot}575T}$$

The absolute, or Kelvin, scale of temperatures is used in all thermodynamical calculations.

The free-energy change, which is the driving force of a reaction, is the difference between the total energy, or enthalpy, change, $\Delta H°$, and the internal energy change. The latter quantity is the product of absolute temperature, T, and entropy change, ΔS. Thus

$$\Delta F° = \Delta H - T.\Delta S$$

* For a more complete list, *see* Chipman.[4]

The following are the values of ΔH and ΔS for the various reactions used in this paper :

Reaction	ΔH, °cal.	ΔS, °cal.
O_2 (gaseous) → 2O (dissolved in Fe)	− 66,120	+ 4·0
S_2 (gaseous) → 2S (dissolved in Fe)	− 84,820	+24·6
Mn (liquid) → Mn (dissolved in Fe)	nil	− 9·1
Si (liquid) → Si (dissolved in Fe)	− 29,000	− 0·7
Fe (liquid) + $\frac{1}{2}O_2$ (gaseous) → FeO (in liquid slag) ...	− 61,960	+14·55
Mn (liquid) + $\frac{1}{2}O_2$ (gaseous) → MnO (in liquid slag) ...	− 92,160	+19·9
Si (liquid) + O_2 (gaseous) → SiO_2 (solid, assumed to be same in liquid slag)	−214,300	+47·0
Fe (liquid) + $\frac{1}{2}S_2$ (gaseous) → FeS (in liquid slag) ...	− 28,000	+10·2
Mn (liquid) + $\frac{1}{2}S_2$ (gaseous) → MnS (solid)	− 65,000	+19·0

These values refer to the energy changes, in calories, when a reaction, involving one gramme-molecule of the first-mentioned reagent, takes place in the direction of the arrow. If the direction of the arrows is reversed, the signs of ΔH and ΔS are reversed. The free-energy equations are combined in exactly the same way as the chemical equations. In the equilibrium constant, the reaction products are placed above the line, and the reagents below. This is shown in the example below :

~~Si (liquid)~~ + ~~O_2 (gaseous)~~	→ SiO_2 (in slag)	: $\Delta F^\circ = -214{,}300 + 47{\cdot}0\,T$
Si (in Fe)	→ ~~Si (liquid)~~	: $\Delta F^\circ = +29{,}000 - 0{\cdot}7\,T$
2FeO (in slag)	→ 2Fe (liquid) + ~~O_2 (gaseous)~~	: $\Delta F^\circ = +123{,}920 - 29{\cdot}1\,T$
Si (in Fe) + 2FeO (in slag)	→ 2Fe (liquid) + SiO_2 (in slag)	: $\Delta F^\circ = -61{,}380 + 17{\cdot}2\,T$

$$K_{\text{Si-Fe}} = \frac{[\text{Fe}]^2(\alpha SiO_2)}{[\text{Si}](\alpha FeO)^2},$$

$$\text{where } \log K = \frac{13{,}420}{T} - 3{\cdot}76$$

APPENDIX II—Method of Calculation by Trial and Error

by E. Bishop

The equations from which the calculation must be made are derived as shown under " Thermodynamic Principles " (p. 161), and are :

Stoichiometric

$$A + 7{\cdot}75 \times 10^{-1}E = \text{Total manganese} \quad \ldots\ldots(1)$$

$$B + 4{\cdot}67 \times 10^{-1}F = \text{Total silicon} \quad \ldots\ldots(2)$$

$$D + 2{\cdot}25 \times 10^{-1}E + 5{\cdot}33 \times 10^{-1}F + 2{\cdot}28 \times 10^{-1}G = \text{Total oxygen} \quad \ldots\ldots(3)$$

Thermodynamic

$$\log \frac{ADK_m}{E} = \frac{12{,}900}{T} + 4{\cdot}05 \ldots(4)$$

$$\log \frac{BD^2K_m}{F} = -\frac{24{,}200}{T} + 7{\cdot}77 \ldots(5)$$

$$\log \frac{DK_m}{G} = -\frac{6{,}320}{T} + 0{\cdot}87 \ldots(6)$$

$$K_m = \frac{E}{71} + \frac{G}{72} + \frac{F}{60} \quad \ldots\ldots(7)$$

Seven equations are obtained containing seven unknowns, but elimination is impracticable. The method adopted for solution is to assume values for B and for D, and to equate the right-hand side and left-hand side of equations (1) and (7). The steps are :

(*a*) Assume a value for B.
(*b*) Find F, by difference, from equation (2).
(*c*) Find F/B and thus D^2K_m from equation (5).
(*d*) Assume a value for D, and divide into D^2K_m, to find DK_m.
(*e*) Calculate G from DK_m, *via* equation (6).
(*f*) Knowing D, F, and G, find E, by difference, from equation (3).
(*g*) Find E/DK_m, and thus A, from equation (4).
(*h*) Find the left-hand side of equation (1), knowing A and E.
(*i*) Select alternative values of D, and proceed from step (*d*) until the sides of equation (1) are equal.
(*k*) Having found the correct value of D, find K_m, by dividing DK_m again by D. This is the left-hand side of equation (7).
(*l*) Also, find the right-hand side of equation (7), using corresponding values of E, F, and G.
(*m*) Select alternative values of B, and proceed as before, first obtaining a suitable D value for equation (1), and testing the result in equation (7), until the two sides of the equation are equal.

References

1. H. A. Sloman, T. E. Rooney, and T. H. Schofield : *Journal of The Iron and Steel Institute*, 1945, No. II, pp. 127p–155p.
2. W. Andrew : *Transactions of the Institute of Welding*, 1945, vol. 8, Aug., p. 119.
3. L. Reeve : *Journal of The Iron and Steel Institute*, 1945, No. II, pp. 385p–396p.
4. J. Chipman : *Transactions of the American Society for Metals*, 1942, vol. 30, Dec., pp. 853–854.
5. W. R. Maddocks : *The Iron and Steel Institute*, 1935, *Carnegie Scholarship Memoirs*, vol. 24, p. 61.
6. C. Benedicks and H. Löfquist : " Non-Metallic Inclusions in Iron and Steel," p. 112 ; London, 1930 : Chapman and Hall.
7. C. A. Zappfe and C. E. Sims : *American Institute of Mining and Metallurgical Engineers, Technical Publication* 1498 : *Metals Technology*, 1942, vol. 9, July.
8. J. H. Whiteley : *Transactions of the Institute of Welding*, 1946, vol. 9, June, p. 108 ; Aug, pp. 138–139.

Micro-Examination and Electrode-Potential Measurements of Temper-Brittle Steels

By D. McLean, B.Sc., and L. Northcott, D.Sc.

SYNOPSIS

The microstructure and impact strength of five alloy steels after various tempering treatments have been correlated, using as etching reagents solutions of picric acid with and without surface-active compounds, one of which has previously been shown to reveal heavy grain boundaries in temper-embrittled steels.[1] In all specimens embrittled either by slow cooling from the tempering temperature or by re-tempering at intermediate temperatures, grain boundaries could be revealed much more markedly than in tough specimens of the same composition, and fracture followed the boundaries.

Detailed micro-examination gave some indication of the character of the grain-boundary material. Fractures of specimens broken at liquid-air temperature to produce intergranular fracture in all were examined at high power, but no difference could be detected between "tough" and "brittle" specimens to suggest an intergranular precipitate in the latter. Electrode-potential measurements on similar fractures did show differences, however, seemingly related to grain-boundary composition. The results indicate that grain-boundary precipitation need not occur for brittleness to set in, and an alternative mechanism of equilibrium segregation is suggested.

Introduction

FREQUENT attempts have been made in the past to differentiate between the microstructures of a steel in the temper-brittle and non-temper-brittle conditions but little success has been attained. Some investigators have claimed to have shown carbides in the grain boundaries of steels in the brittle condition, but the evidence is not at all clear and it is usually considered that the microstructures of the steel in the tough and brittle conditions are identical.

During an investigation with certain non-ferrous alloys,[2] a phenomenon similar to that of temper-brittleness in steels was observed, the material being brittle when slowly cooled after tempering at 650° C., but tough when quenched from that temperature. The phenomenon was shown to be associated with the constitution of the alloy, the solubility of the second phase being appreciably greater at elevated than at low temperatures, but it was only by careful metallographic work that a grain-boundary effect could be shown under the microscope.

A somewhat similar state of affairs was suspected to occur in temper-brittle steels, and attention was directed to this problem by a paper appearing about this time by Cohen, Hurlich, and Jacobson.[1] These investigators described an etching solution capable of differentiating between a steel when in the brittle or tough condition. This reagent consists of picric acid and "Zephiran chloride" dissolved in ether; Zephiran chloride is a trade name for an American germicide and consists of a mixture of high-molecular alkyl-dimethyl-benzyl ammonium chlorides. It is a surface-active agent. It seemed clear that this type of reagent ought to be investigated on a range of steels. The material is not generally available in this country but promising results were obtained with a British-made surface-active agent belonging to the same family of quaternary ammonium compounds when examining a nickel–chromium–molybdenum steel. A range of these reagents was first tried out on steel specimens water-quenched and furnace-cooled from the tempering temperature, and the more promising agents were then used on specimens re-tempered to intermediate temperatures in order to examine more fully the correlation between grain-boundary intensity and impact strength. This work suggested other lines of attack, and preliminary results of some are reported here. The detailed changes in microstructure with different reagents and times of heating were observed, and fractographic studies and electrode-potential measurements were made on fractures, some arranged to be intergranular. The results have suggested a tentative theory of the mechanism of temper-embrittlement.

REAGENTS AND STEELS USED

Many surface-active agents are available and the following were selected for detailed study:

(1) Zephiran chloride (alkyl-dimethyl-benzyl ammonium chloride).

(2) Cetyl-trimethyl ammonium bromide (abbreviated to CTAB), a similar British-made compound. (Cetyl is the alkyl radical $C_{16}H_{33}$.)

In (1) and (2) the long organic chain forms the positive ion.

(3) Common soap, since it is readily obtainable.

(4) Shellestol (Teepol), a sodium alkyl sulphate.

(5) Aryl ether of polyethylene glycol (abbreviated to Aryl EPG), a long-chain compound having a number of double bonds in the chain.

(6) Tri-cresyl phosphate, an adsorbing rather than a wetting agent.

(7) Lorol alcohol (normal dodecyl alcohol).

(8) English lecithin with the ether replaced by benzene, since a benzene solution is more pleasant to handle.

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In (3), (4), and (7) the long organic chain forms the negative ion.

These were made up into etching reagents in a manner similar to that described by Cohen, Hurlich, and Jacobson. The surface-active agent and the picric acid were added to 100 ml. of water (distilled), 100 ml. of ether were added, and the mixture was shaken vigorously, and allowed to stand for 24 hr. before use. Separation into two layers occurred. The upper ethereal layer was used for etching purposes and was returned to the stock bottle after use. Ether was gradually lost by volatilization, but fresh ether could be added to compensate for loss without affecting the etching behaviour. The water layer serves as a convenient reservoir of picric acid and agent, and as the ether becomes saturated with water, its ionizing capacity should be increased.

For comparison purposes the following standard etching reagents were also examined: Saturated aqueous picric acid, saturated alcoholic picric acid, and 2% nitric acid in alcohol. Tests with these solutions were also made after addition of Aryl EPG. A further reagent was studied—an acetic acid + Aryl EPG solution. Aryl EPG was selected as it proved to be the most effective of the special agents.

A complete list of the etching reagents used is given in Table I.

In addition to the above, a few trials were made with other materials having a wetting or bonding action.

The compositions of the steels used for this investigation are given in Table II. All except the nickel–chromium–molybdenum steel had been used in previous investigations on temper-brittleness,[3] and only the nickel steel had been found to be non-susceptible.

BRITTLENESS PRODUCED BY SLOW COOLING

Four Izod notched-bar impact specimens from each composition were rough-machined and marked 1 to 4. The nickel–chromium–molybdenum samples had to be obtained from odd pieces having uncertain and possibly different histories, but each of the other sets was obtained from a single piece. All specimens were heated for 1 hr. at 900° C., oil-quenched, and then treated as follows:

Sample 1—treatment A—Tempered for 2 hr. at 635° C. and water-quenched.
Sample 2—treatment B—As treatment A, re-tempered for 2 hr. at 635° C. and slowly cooled.
Sample 3—treatment C—Tempered for 2 hr. at 635° C. and slowly cooled.
Sample 4—treatment D—As treatment C, re-tempered for 2 hr. at 635° C. and water-quenched.

The slow cooling consisted of furnace cooling from 635° C. to 480° C. in 2½ hr., maintaining at 480° C. for 20 hr., then furnace cooling to room temperature (5 hr. to cool to 220° C.). Specimens for micro-examination were cut-off, the remaining length finish-machined, and the Izod tests performed. The results of these tests are given in Table III.

The susceptibility ratio (*see* Table III) is the ratio of the impact strengths of specimens No. 1 : No. 3. The results confirm the previous finding[3] and, in addition, show that the nickel–chromium–molybdenum steel is mildly susceptible.

During the etching trials precautions were taken to ensure reliable results, and each set of four specimens was mounted together in bakelite to ensure similarity of polishing and etching treatment.

The results of the etching trials are summarized in Table IV; in cases where no discrimination was observed "No" is inserted; this occurred only when

Table I
COMPOSITION OF ETCHING REAGENTS

Abbreviated Name	Composition
(1) 2% Nital	2% conc. HNO_3 in industrial methylated spirits
(2) Aqueous picric	Saturated solution of picric acid in water
(3) Aqueous picric + 1% Aryl EPG	As (2) + 1% by volume Aryl ether of polyethylene glycol
(4) Alcoholic picric	Saturated solution of picric acid in industrial methylated spirits
(5) Alcoholic picric + 1% Aryl EPG	As (4) + 1% by volume Aryl ether of polyethylene glycol
	Ethereal-Aqueous Picric Solutions
(6) Ethereal picric	20 g. picric acid + 100 ml. water + 100 ml. ether
(7) 4% Zephiran chloride	As (6) + 4 ml. alkyl dimethyl benzyl ammonium chloride
(8) 0·3% CTAB	As (6) + 0·3 g. cetyl trimethyl ammonium bromide
(9) 1% CTAB	As (6) + 1·0 g. cetyl trimethyl ammonium bromide
(10) 1% Soap	As (6) + 1·0 g. soap
(11) 1% Shellestol (Teepol)	As (6) + 1 ml. sodium alkyl sulphate
(12) 1% Aryl EPG	As (6) + 1 ml. Aryl ether of polyethylene glycol
(13) 1% Tri-cresyl phosphate	As (6) + 1 ml. Tri-cresyl phosphate
(14) 1% Lorol alcohol	As (6) + 1 g. normal dodecyl alcohol
(15) 1% Lecithin	20 g. picric acid + 100 ml. water + 100 ml. benzene + 1 ml. lecithin
	Containing 1% Aryl EPG + :
(16) 0·5% Nitric acid	0·5 ml. conc. HNO_3 + 100 ml. water + 100 ml. ether + 1 ml. Aryl ether of polyethylene glycol
(17) 1% Acetic acid	1 ml. glacial acetic acid + 100 ml. water + 100 ml. ether + 1 ml. Aryl ether of polyethylene glycol

Distilled water only was used in making up these solutions

Table II

COMPOSITIONS OF STEELS USED

Type	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %
Ni	0·42	0·15	0·17	0·036	0·021	3·09	0·01	...
Ni–Cr–Mo	0·34	0·27	0·60	...	...	3·55	1·72	0·56
Ni–Cr	0·31	0·13	0·46	0·036	0·023	3·62	0·82	...
Cr–Mn	0·55	0·18	0·91	0·018	0·026	Nil	1·73	...
Ni–Mn	0·43	0·15	1·60	0·017	0·028	2·96	0·09	...

no grain boundaries were revealed. The numbers indicate the etching times in minutes which enabled ample discrimination to be made between the brittle specimens (2 and 3 slowly cooled, treatments B and C) and the tough specimens (1 and 4 rapidly cooled, treatments A and D) according to the relative intensity of the grain boundaries as shown in the photographs discussed below. Reliable discrimination was generally possible, especially at high magnifications, in much shorter times than these. There were few doubtful cases.

It will be seen that the etching behaviour can give a reliable indication of temper-brittleness, but that not all reagents are equally successful. Of the "standard" etchants, nitric acid gives no indication. Aqueous picric acid revealed grain boundaries better in slowly cooled specimens (treatments B or C) than in specimens rapidly cooled (treatments A or D); with the chromium-bearing steels the difference was easily sufficient for satisfactory discrimination. In view of the general belief that no microstructural difference can be detected between tough and brittle specimens of susceptible steels this was surprising since aqueous picric acid is a well-known reagent, but it was confirmed several times, although the rate of etching and intensity of grain boundaries varied somewhat with picric acid from different sources, probably because "pure" picric acid contains 1 or 2% of impurities which are surface-active. Deliberate addition of 1% Aryl EPG to the aqueous picric acid solution neither increased the rate of etching nor improved discrimination. Alcoholic picric acid only discriminated in two cases after very prolonged etching. Here again addition of 1% Aryl EPG did not increase the rate of etching and no discrimination was obtained with any of the steels during etching lasting for 30 min. The ethereal solutions of picric acid discriminated satisfactorily between slowly and rapidly cooled chromium-bearing specimens. Two solutions, No. 7 (containing 4 ml. of Zephiran chloride) and No. 9 (containing 1 g. of CTAB), discriminated also between slowly and rapidly cooled nickel–manganese specimens after repeated etching and polishing (employing light etches and light polishes which only partially removed the previous etch) and one, No. 5 (containing Aryl EPG), discriminated on the first etch between these specimens as well as between the chromium-bearing ones. Solutions containing other agents also discriminated satisfactorily between brittle and tough specimens except in the case of the nickel–manganese steel. The Zephiran chloride, CTAB, and Aryl EPG etchants developed grain boundaries more distinctly than other reagents and also revealed sub-boundaries in slowly cooled specimens.

With all the steels the etching behaviours of the No. 1 (treatment A, water-quenched) and No. 4 (treatment D, furnace cooling, followed by water-quenching) specimens were similar and so were those of the No. 3 (treatment C, slowly cooled) and No. 2 (treatment B, water-quenched followed by slow cooling) specimens. This is in agreement with the impact strengths. Over the four susceptible steels, however, the variation in grain-boundary intensity from steel to steel in the slowly cooled condition did not tally with the impact strength, the extreme instance being that the grain boundaries of the nickel–manganese steel were not etched at all by reagents

Table III

IZOD NOTCHED-BAR IMPACT TEST ON SPECIMENS WATER-QUENCHED OR SLOWLY COOLED AFTER TEMPERING AT 635° C.

Type of Steel	Izod Value, ft. lb., after Tempering Treatment				Susceptibility Ratio	
	A	B	C	D	Present Work	Previous Work[2]
Ni	34·8	35·5	36·9	33·3	0·94	1·0
Ni–Cr–Mo	60·0	28·4	30·0	62·2	2·0	...
Ni–Cr	65·1	11·2	14·3	68·4	4·6	4·05
Cr–Mn	48·1	3·1	1·8	55·2	26·7	25·5
Ni–Mn	51·6	2·0	0·9	75·3	56·7	29·5

All specimens oil-hardened from 900° C.; each result is a single test
A—Tempered and water-quenched
B—Tempered and water-quenched, re-tempered and slowly cooled
C—Tempered and slowly cooled
D—Tempered and slowly cooled, re-tempered and water-quenched

Table IV

RESULTS OF ETCHING TRIALS, SHOWING WHETHER OR NOT THE ETCHANT DISCRIMINATES SATISFACTORILY BETWEEN SLOWLY AND RAPIDLY COOLED SPECIMENS

Numbers give etching times in minutes for satisfactory discrimination

Type of Steel	Etching Reagents															Susceptibility Ratio
		Aqueous Picric		Alcoholic Picric		Ethereal Aqueous Picric (Upper Layer of Ether-Water Mixture)								1% Aryl EPG		
	2% Nital (1)	Alone (2)	+1% Aryl EPG (3)	Alone (4)	+1% Aryl EPG (5)	Alone (6)	+4% Zephiran Chloride (7)	+0·3% C.T.A.B. (8)	+1% C.T.A.B. (9)	+1% Soap (10)	+1% Shell-estol (11)	+1% Aryl EPG (12)	+1% Tri-Cresyl Phosphate (13)	+1% Lorol Alcohol (14)	+1% Lecithin* (15)	+0·5% Nitric Acid (16)	+1% Acetic Acid (17)	
Ni	No	No	No	No	No	No	No	No	No	No	No	No	No	No	?	No	No	0·94
Ni–Cr–Mo‡	No	12	32	No	No	16	12	12	8	12	12†	12	12	12	8	No	No	2·0
Ni–Cr	No	6	8	56	No	4	8	8	6	4	8†	8	8	8	9	No	No	4·6
Cr–Mn	No	4	8	32	No	8	6	8	6	8	8†	6	4	4	6	No	No	26·7
Ni–Mn	No	Poor	Poor	No	No	No	Yes§	No	Yes§	No	No	‡	No	No	?	No	No	56·7

* Ether replaced by benzene. This etchant stained so badly that in two cases the true etch could hardly be discerned, but possible grain boundaries could occasionally be distinguished in the slowly cooled Ni–Mn specimens

† Numerous blackened areas rendered the etch unsightly under the microscope

‡ Grain boundaries were readily shown up in slowly cooled samples of another Ni–Cr–Mo steel

§ Satisfactory discrimination only after repeated etching and polishing. (See text)

successful with the other steels. This suggests that the embrittling material may vary from steel to steel.

The structures are shown in Figs. 1–25 and 27–30. Figures 1–15 show the structures of the slowly cooled specimens (No. 3's) after etching for the times shown in Table IV. Figures 1–5 are etched in nitric acid (solution No. 1) and Figs. 11–15 in alcoholic picric acid (No. 4); the structures of the water-quenched specimens were indistinguishable. Figures 6–10 are etched in aqueous picric acid (No. 2); the structures of the water-quenched specimens were similar, apart from the relative absence of grain boundaries. The structures yielded by Aryl EPG (No. 12) are shown in Figs. 16–25. Figures 16–20 are the water-quenched structures and Figs. 21–25 the slowly cooled structures. Discrimination in each pair is good for the susceptible steels, including the nickel–manganese steel. Aryl EPG is the most successful special addition in revealing grain boundaries and sub-boundaries, although it tends to stain.

Grain boundaries invariably stood out more clearly if the specimens were lightly repolished after etching. This is shown in Figs. 27–30, where Fig. 27 shows the chromium–manganese slowly cooled specimen etched with Zephiran chloride (No. 7) and Fig. 28 shows the same specimen after light polishing. It is quite clear that the grain boundary is etched more deeply than the grain interior. For this reason repeated etching and polishing can accentuate the grain-boundary appearance. The grain boundaries in the slowly cooled nickel–manganese specimen were undiscernible after one etch with CTAB (No. 9), but stood out emphatically after several etches and polishes—Fig. 30. The water-quenched specimen after the same treatment showed no boundaries—Fig. 29.

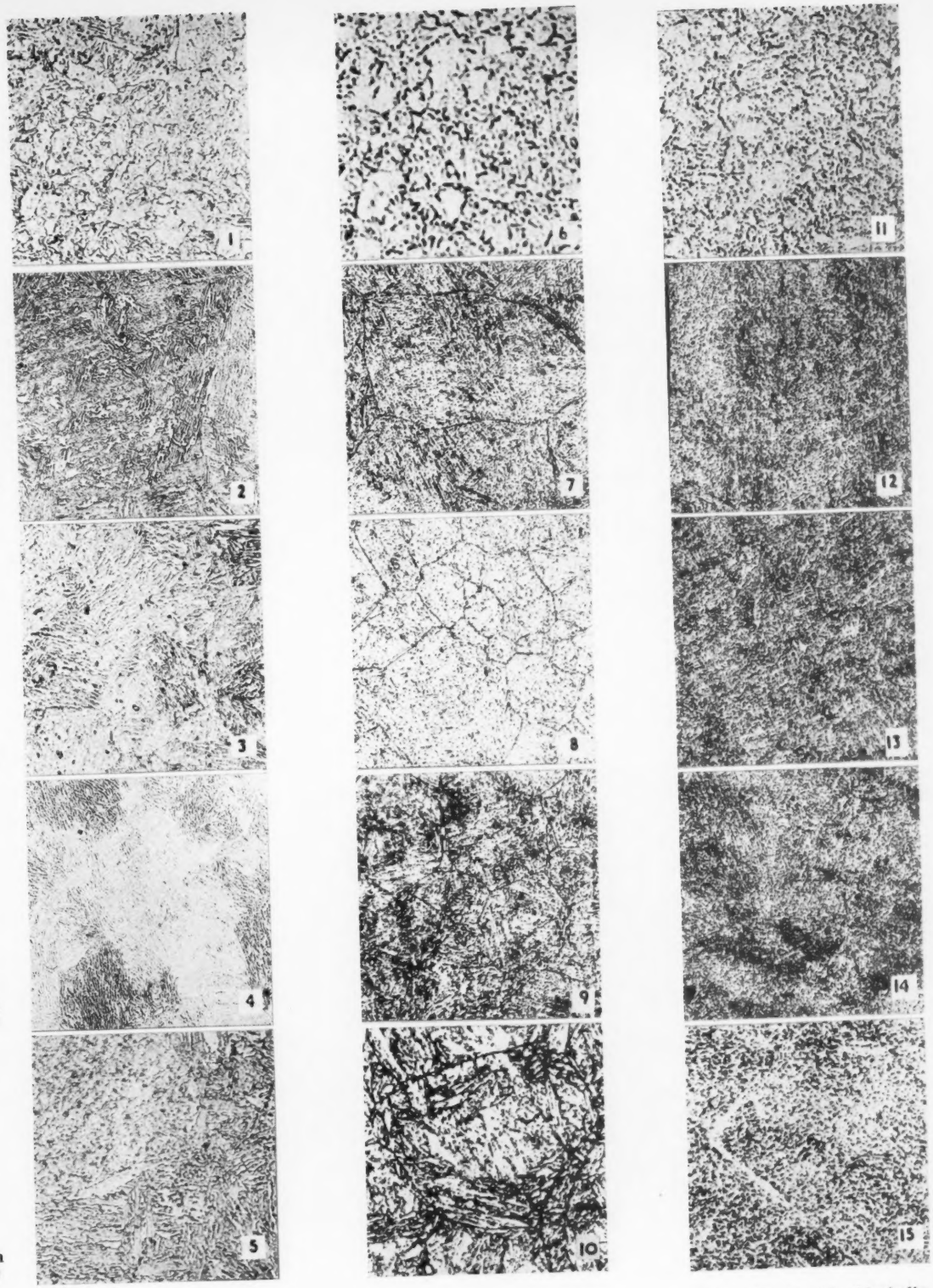
In the rapidly cooled chromium-bearing steels prolonged etching usually developed the grain boundaries to a point where, without a comparison specimen, they could be mistaken for slowly cooled specimens. It is therefore advisable that comparison specimens, tough and brittle, mounted side by side, should be employed at least until familiarity is gained with any particular steel.

BRITTLENESS PRODUCED BY RE-TEMPERING

Specimens were oil-quenched from 900° C., tempered for 2 hr. at 635° C., and water-quenched, and then re-tempered for 1 day at various temperatures. Izod tests were carried out and sections micro-examined using the etching reagents found to be satisfactory in the previous section. The Izod results are given in Table V, and those for the nickel, nickel–chromium, and nickel–manganese steels are plotted in Fig. 26.

The susceptible steels all lose impact strength when re-tempered at 500° C., but the non-susceptible steel suffers no drop in impact strength at this temperature; these results are normal.

Photographs of microstructures, lightly repolished after etching, are superimposed on the graphs in Fig. 26. For any one steel the six micro-specimens were mounted in bakelite in two groups of three and treated identically. Broadly speaking, the micro-structures follow the impact curves, *i.e.*, where the



Figs. 1 to 5—Alcoholic nitric (No. 1)

Figs. 6 to 10—Aqueous picric (No. 2)

Figs. 11 to 15—Alcoholic picric (No. 4)

Figs. 1 to 15—Microstructures revealed by various etching reagents. All specimens slowly cooled

[*McLean and Northcott*

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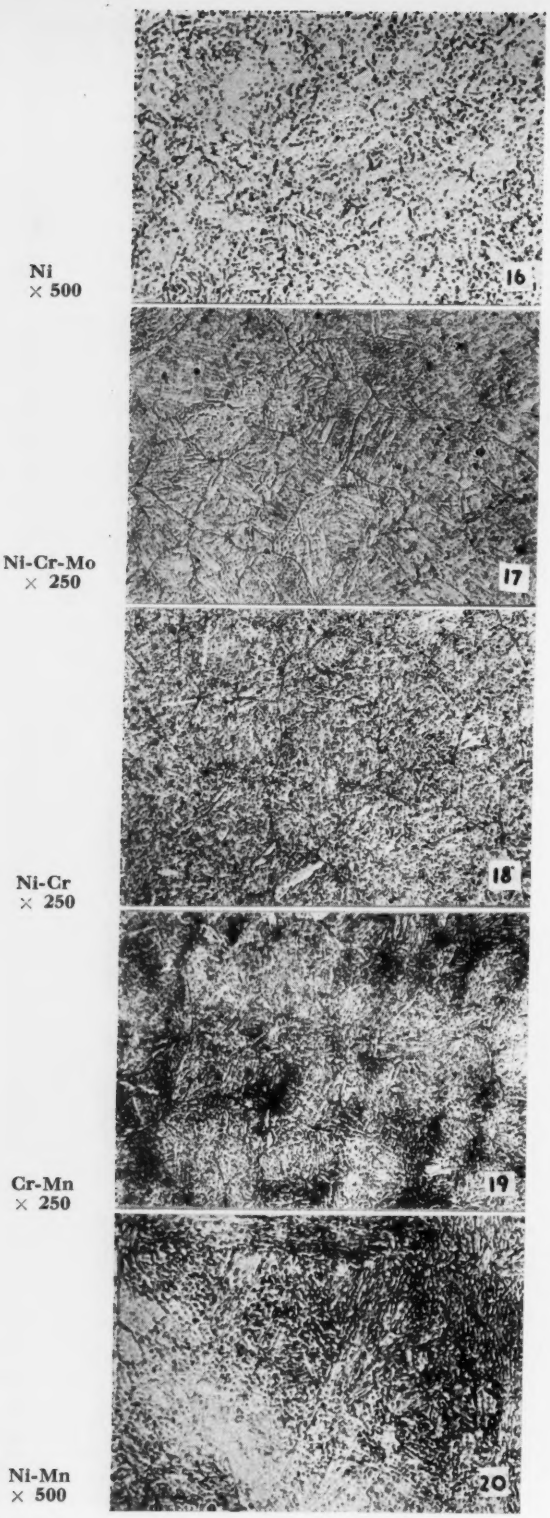
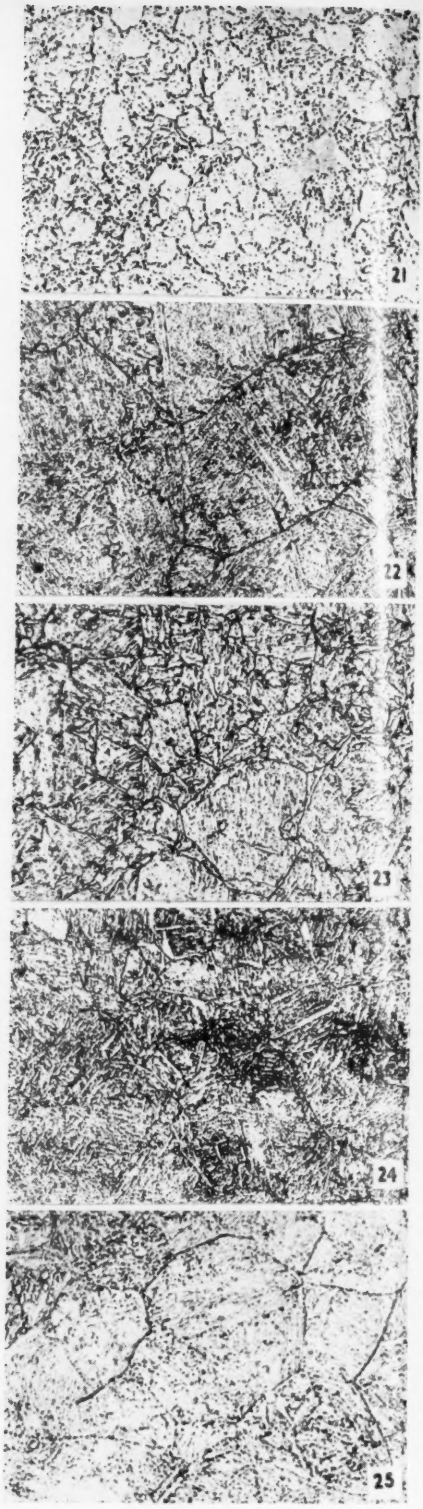


Figs. 16 to 20—Specimens water-quenched



Figs. 21 to 25—Specimens slowly cooled

Figs. 16 to 25—Microstructures revealed by etching with Aryl EPG (No. 12)

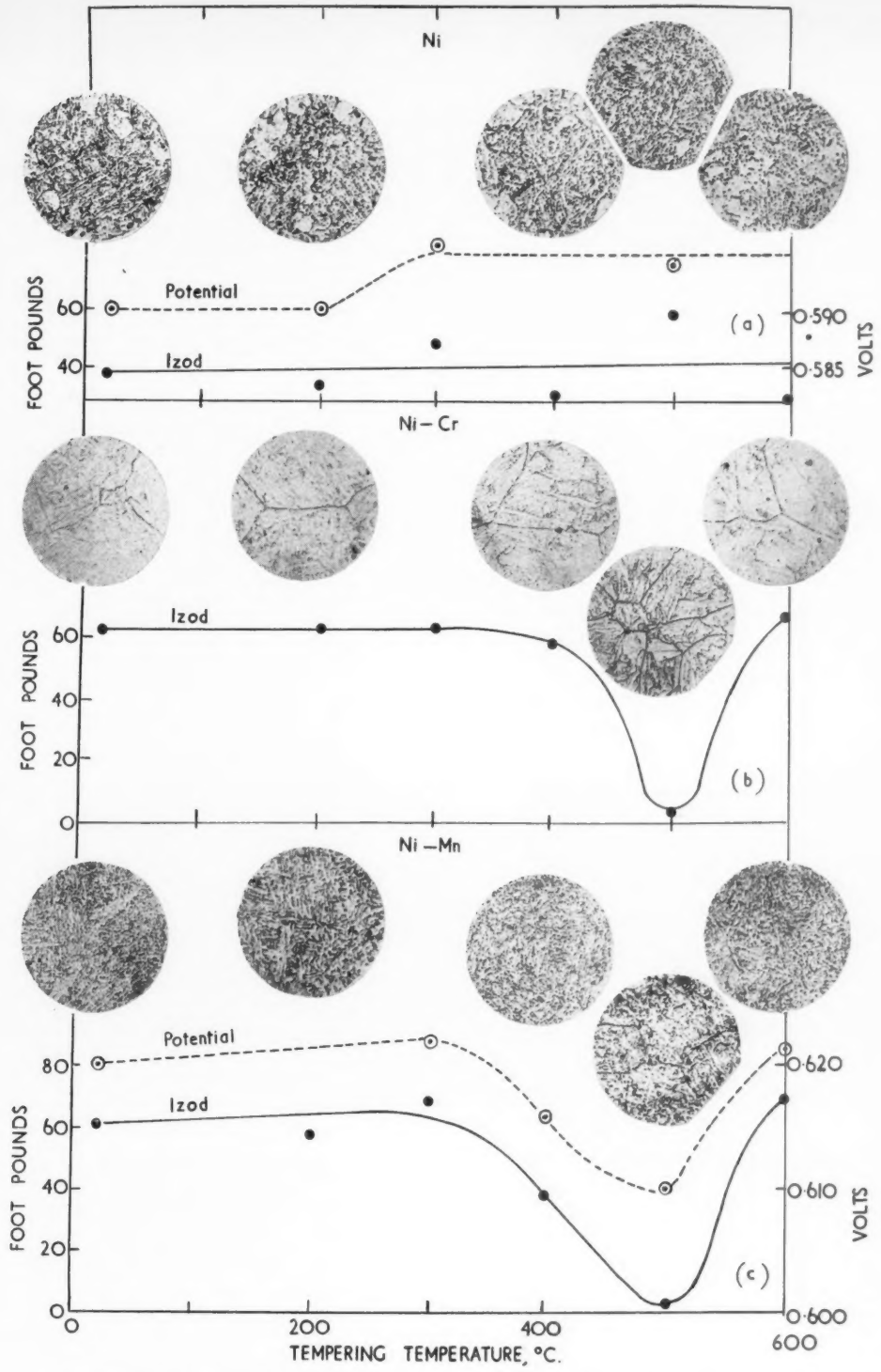


Fig. 26—Impact strength, electrode potehtial, and microstructure of tempered steels

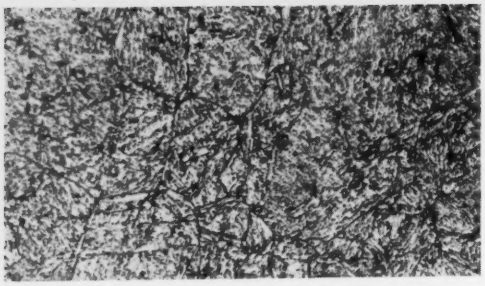


Fig. 27—Cr Mn steel, slowly cooled, and etched with Zephiran chloride × 250

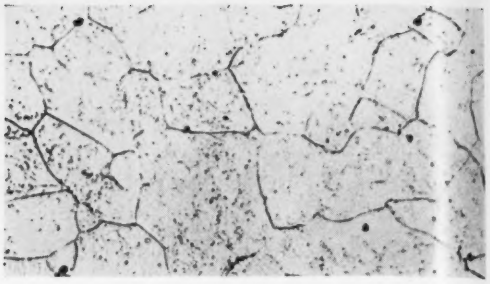


Fig. 28—As Fig. 27, but lightly repolished × 250

Fig. 29—Water-quenched from 635° C.

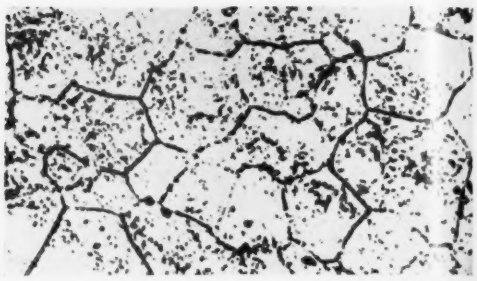


Fig. 30—Slowly cooled from 635° C.

Figs. 29 and 30—Ni-Mn steel alternately etched with CTAB and repolished six times × 250

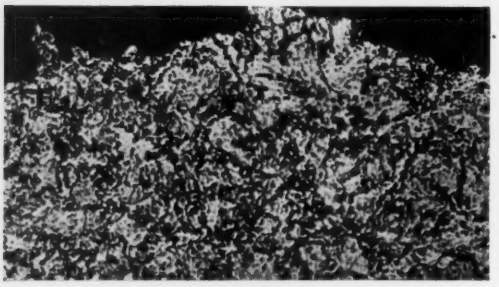


Fig. 31—Ni steel, water-quenched. Transcrystalline fracture × 350

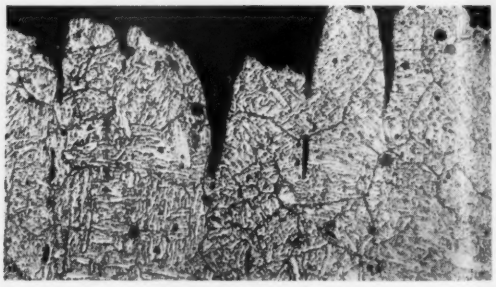


Fig. 32—Ni-Cr steel, water-quenched. Transcrystalline fracture × 250

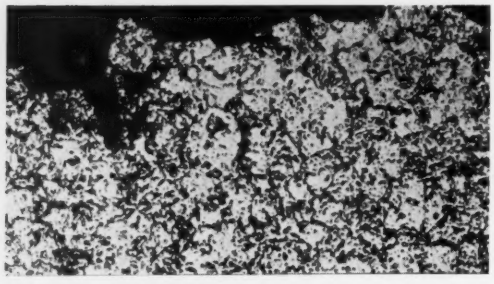


Fig. 33—Ni steel, slowly cooled. Transcrystalline fracture × 350

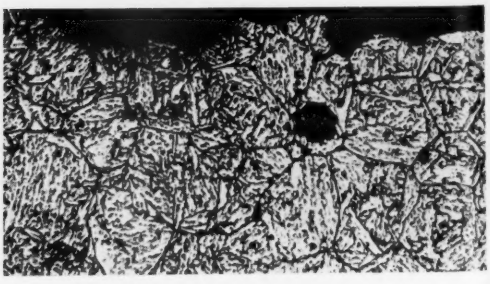


Fig. 34—Ni-Cr steel, slowly cooled. Intercrystalline fracture × 250

Figs. 31 to 34—Transverse sections through fractures. Specimens etched with CTAB (No. 8)

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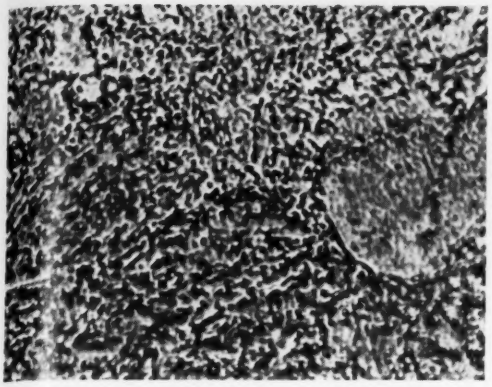

Fig. 35

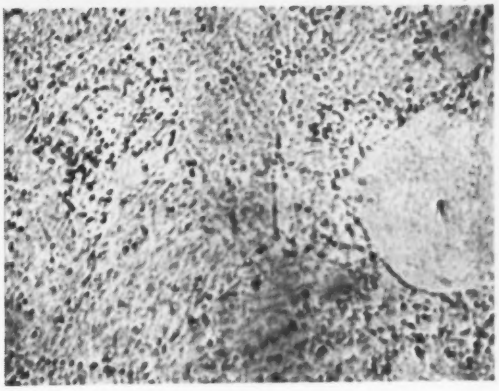

Fig. 36

Figs. 35 and 36—Water-quenched from 635° C.

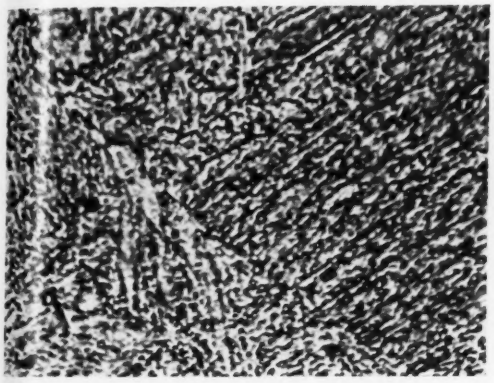

Fig. 37

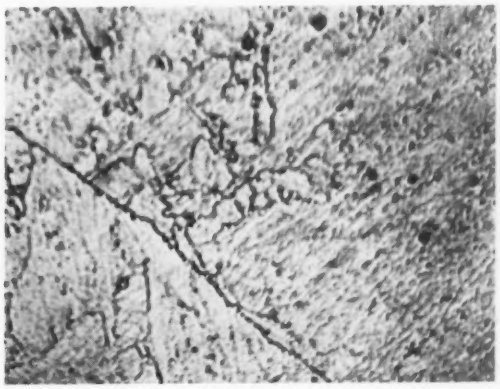

Fig. 38

Figs. 37 and 38—Slowly cooled from 635° C.

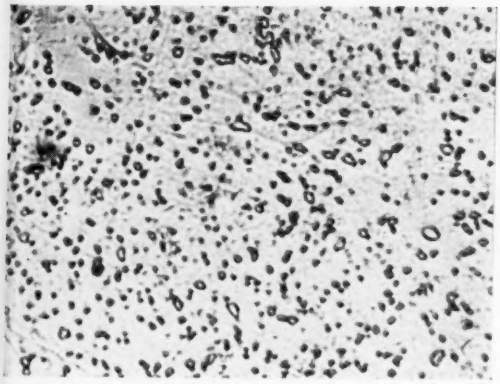

Fig. 39

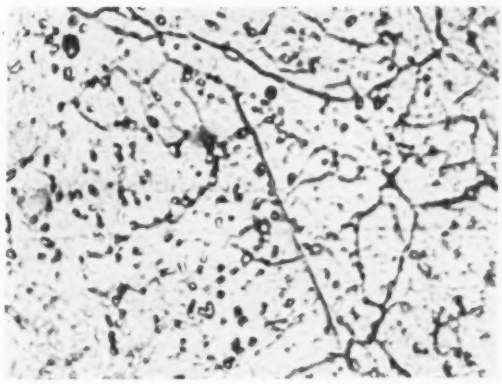

Fig. 40

Figs. 39 and 40—After three months at 500° C.

Figs. 35, 37, and 39—Etched with alcoholic picric (No. 4)

Figs. 36, 38, and 40—Etched with Aryl EPG (No. 12)

Figs. 35 to 40—Ni-Cr steel specimens × 2000

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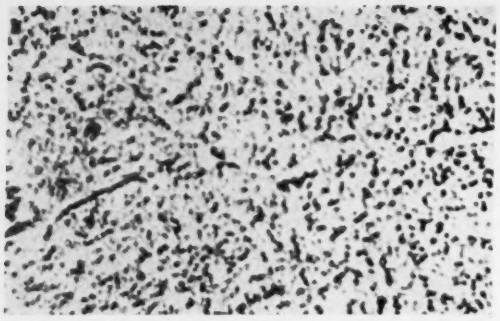

Fig. 41—After three months at 500° C. Etched with alcoholic picric

Fig. 42—Same field as Fig. 41, but etched with Aryl EPG.

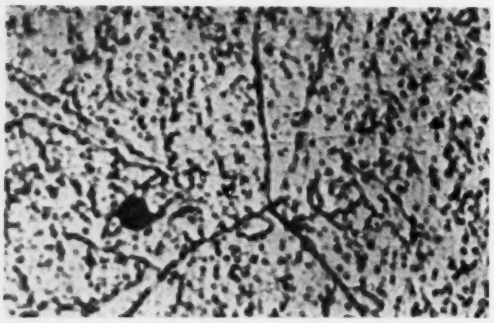

Fig. 43—Same specimen as Fig. 42, but with a lighter etch with Aryl EPG

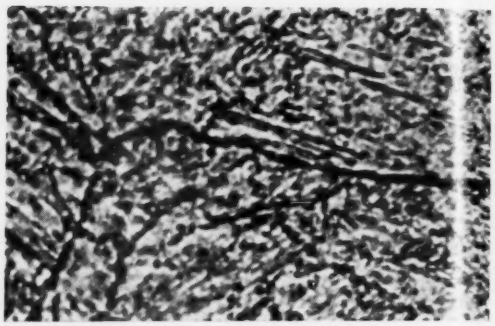

Fig. 44—After 2 hr. at 635° C., slowly cooled. Etched with Aryl EPG for same time as with Fig. 42

Figs. 41 to 44—Ni-Cr-Mo steel specimens × 2000

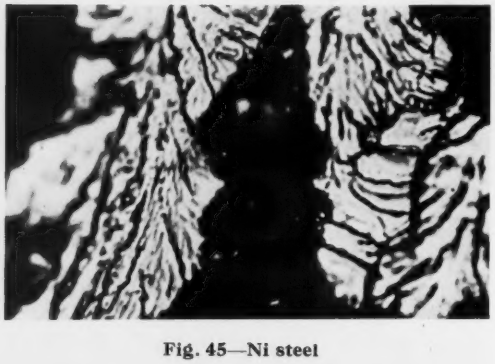

Fig. 45—Ni steel

Fig. 46—Ni steel

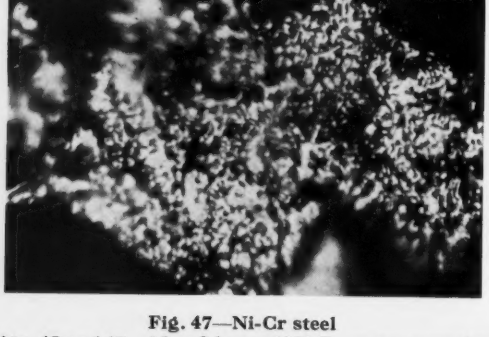

Fig. 47—Ni-Cr steel

Figs. 45 and 47—After 2 hr. at 635° C., water-quenched

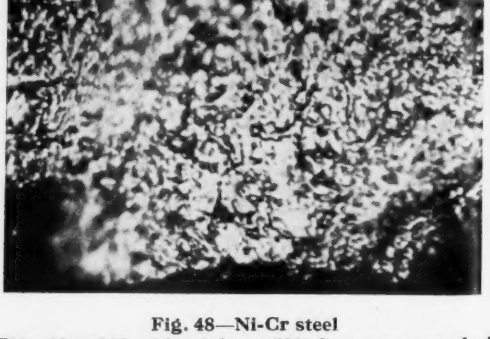

Fig. 48—Ni-Cr steel

Figs. 46 and 48—After 1 day at 500° C., water-quenched

Figs. 45 to 48—Fractures produced at liquid-air temperature × 2000

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Table V

IMPACT STRENGTHS AFTER RE-TEMPERING

All specimens oil-hardened from 900° C., tempered at 635° C., and water-quenched

Steel	Izod Tests at Room Temperature, ft. lb.*						Tests at Liquid-Air Temp.†		
	As W.Q. from 635° C.	Re-tempered for 1 day at and water-quenched from:					As W.Q. (1)	1 day 500° C. (2)	Ratio (1)/(2)
		200° C.	300° C.	400° C.	500° C.	600° C.			
Ni	36	34	47	31	58	30	2·4	2·1	1·1
Ni–Cr–Mo	60	57	58	55	43	62	8·8	3·1	2·8
Ni–Cr	64	64	65	60	4·1	67	3·5	2·2	1·6
Cr–Mn	32	37	42	36	6·6	52	...	...	...
Ni–Mn	61	57	68	38	2·4	68	3·7	2·2	1·7

* Izod machine † Charpy machine but Izod specimens

impact strength drops appreciably the delineation of grain and sub-boundaries becomes much more marked. There are, however, smaller variations in grain-boundary appearance visible at high magnifications which are unaccompanied by a change in impact strength. For example, the boundaries of the susceptible steels after tempering at 600° C. show a slight tendency to break up and are more pronounced than after tempering within the range room-temperature–400° C., without there being a difference in impact strength. The microstructures of the nickel–chromium–molybdenum and chromium–manganese steels reproduced the features of the nickel–chromium and nickel–manganese steels. Comparing the four susceptible steels tempered at 500° C., the grain-boundary intensity from steel to steel did not agree with the impact strength, much as with the slowly cooled specimens in the previous section.

TYPES OF FRACTURES

The fractures of four of the Izod specimens of the nickel and nickel–chromium steels are shown in Figs. 31–34. Those of the two water-quenched specimens and of the slowly cooled nickel (non-susceptible) steel are transcrystalline, but the fracture in the slowly cooled nickel–chromium (susceptible) steel is mostly intercrystalline. The other three steels showed similar behaviour on fracture to the nickel–chromium steel.

Since the embrittled fracture is intergranular, it seems reasonable to associate it with the heavy grain boundaries in embrittled specimens.

MICRO-EXAMINATION OF THE GRAIN-BOUNDARY CONSTITUENT

It is clear from the photographs discussed above that the embrittled specimens contain what appears to be a grain and sub-boundary constituent in considerably greater amount than do the tough samples. Two metallographic lines of attack were made to obtain more information about this "constituent."

The first consisted of examining the same specimen area after etching with different reagents, lightly re-polishing between each etch. In principle, it is possible to distinguish between two alternatives, (*a*) that this constituent is different from the one, presumably a carbide, generally present and revealed by alcoholic picric acid, and (*b*) that it is the same constituent but occurring in much smaller particles. Typical photographs, Figs. 35–38, of the nickel–chromium steel, etched with alcoholic picric acid and Aryl EPG (Nos. (4) and (12) respectively, Table I) show that not only does alcoholic picric acid fail to etch-up the constituent revealed by Aryl EPG, but that Aryl EPG fails to etch-up the constituent revealed by alcoholic picric acid. Were the difference between the two constituents simply a matter of particle size, this difference in etching behaviour would be unlikely. It appears that alternative (*a*) therefore applies. If alcoholic picric acid reveals carbide, there must then be present some constituent other than this carbide. Besides occurring in the grain and sub-boundaries, it also occurs in small amount in the grain interior. With the other steels the etching differences apart from the grain-boundary etch were ill-defined.

The second line of attack was to examine the changes in microstructure after prolonged heating at the embrittling temperature of 500° C. to see if the grain-boundary "constituent" coalesced into distinguishable particles. Specimens were examined after heating for one month and for three months. Except in the nickel steel little change had occurred after one month, but after three months the coalescence of carbides was quite pronounced in all compositions. This indicates the existence of an incubation period, perhaps dependent on the time the precipitating atoms take to diffuse between particles. Typical photographs of the same specimen areas of the nickel–chromium steel, etched with the same reagents as used for Figs. 35–38, are reproduced in Figs. 39 and 40. Despite the carbide coalescence, the grain boundaries shown up by the Aryl EPG are similar to those after heating for only one day, Fig. 38, suggesting that these boundaries represent an equilibrium phenomenon. Similar photographs of the nickel–chromium–molybdenum steel are reproduced in Figs. 41 and 42. The chief differences compared with the nickel–chromium steel are the occurrence in some areas, after three months, of sufficient particles in network form to outline the grain boundaries, and that the grain boundaries revealed by Aryl EPG are thick enough either to be composed of a further phase

or to consist of channels. No difference was detected between the grain-boundary and grain-interior particles in their response to alcoholic picric acid, Aryl EPG, Murakami's reagent, or alkaline sodium picrate, so it is probable that both are the same carbide phase. During repolishing, the carbide particles disappeared first and the boundaries remaining gradually narrowed and finally disappeared, behaving just as channels would be expected to. After a lighter etch with Aryl EPG the boundaries were much finer in between the particles, Fig. 43. On the other hand, the slowly cooled nickel–chromium–molybdenum specimen of Fig. 22, after etching for the same time as Fig. 42 had the grain-boundary appearance shown in Fig. 44, which is similar to that of Fig. 42. The three-month anneal has therefore again produced no obvious change in the boundaries between the particles.

The behaviour of the chromium–manganese steel was intermediate between that of the nickel–chromium and nickel–chromium–molybdenum steels. The nickel and nickel–manganese steels were not investigated.

FRACTOGRAPHIC EXAMINATION

Fractures of the nickel, nickel–chromium, and chromium–manganese steels produced by breaking at liquid-air temperature were examined microscopically on the lines of Zappfe's technique of fractography.[4] Before immersing in liquid air the steels were heat-treated either by water-quenching from 635° C. or by tempering for 1 day at 500° C., corresponding (for the susceptible steels) with the tough or brittle condition respectively at room temperature. At the temperature of test, all the specimens were very brittle (*cf.* results in the right-hand part of Table V) and micro-examination of sections confirmed that fracture was mostly intergranular except in the nickel steel in which, because of its small grain-size, only about 30% of the fracture could be characterized thus. Typical fractures are shown in Figs. 45–48.

No important difference was detected between the two conditions for any of the steels, and in particular no sign of a precipitate was seen on the fractures of the brittle (at room temperature) susceptible steels. There is, however, a noticeable difference between the non-susceptible and the susceptible specimens. The leaf-like areas of the non-susceptible nickel steel (Figs. 45 and 46) consisted of clear flat surfaces of high reflectivity separated by curved dark lines which are presumably steps, whereas the facets of the nickel–chromium (Figs. 47 and 48) and chromium–manganese steels had almost the appearance of containing a considerable number of minute particles. The boundaries of these were incomplete, however, and it is probable that they represent minute irregularities on the fracture surface. In the nickel-steel specimen tempered at 500° C. a few facets similar to the typical susceptible ones were found; in the similarly heat-treated nickel–chromium steel specimen there were a few leaf-like areas similar to those typical of the nickel steel, and in the nickel–chromium steel specimens quenched from 635° C. rather fewer. Etching darkened still further the dark lines on the nickel-steel leaf-like areas and the short irregular lines (" particle " boundaries) on the nickel–chromium and chromium–manganese steel facets without in any case producing noticeable general attack.

Room-temperature fractures were also examined. The structure of the facets of the nickel–chromium and chromium–manganese steels was the same as before, irrespective of heat-treatment condition, although the facets of tough specimens were considerably less flat, presumably owing to the irregular transcrystalline nature of the fracture. Only one nickel-steel fracture was available, in a sample notched with a saw-cut. The fracture was of the " picture-frame " type, the edge being fibrous and the centre somewhat crystalline. The fibrous part had the same structure as the other two steels. About half of the crystalline part also had this structure, but the rest of this part was similar to the liquid-air leaf-like fractures of Figs. 45 and 46.

It is thought that Figs. 47 and 48 represent intercrystalline fracture and the leaf-like areas of Figs. 45 and 46 fracture along cleavage planes.

ELECTRODE-POTENTIAL MEASUREMENTS OF FRACTURES

Electrode-potential measurements were made on the fractures of some of the Izod specimens.

Preliminary trials were made using an N/10 solution of potassium chloride on specimens which had been water-quenched or slowly cooled from the tempering temperature. All the immersed part of each specimen, excluding the chosen area of the fracture, was insulated with paraffin wax, and the measurements were made with a valve-type *p*H meter and a glass counter-electrode.

The general result was that the potential commenced about 0·25 V. negative and drifted in the negative direction for at least 24 hr. The curves obtained for the nickel–chromium and nickel–manganese steels in the two heat-treatment conditions differed by about 40 mV., but for the nickel steel were very similar. The slowly cooled specimen was negative with respect to the water-quenched specimen for the nickel–chromium composition and positive for the nickel–manganese composition. From this it was concluded that the difference was due at least partly to differences in composition of the transcrystalline and intercrystalline fracture surfaces and not only to differences in strain, which would be expected to cause a difference in the same sense for all compositions.

Trials were also made using several other solutions. On balance, for rate of disappearance of drift and magnitude of difference between the two heat-treatment conditions, N/10 ferrous chloride solution seemed best and was used for further work. In addition, the glass electrode was replaced by a saturated calomel electrode. The values given later are those taken 10 min. after immersion when the rate of drift had become negligible.

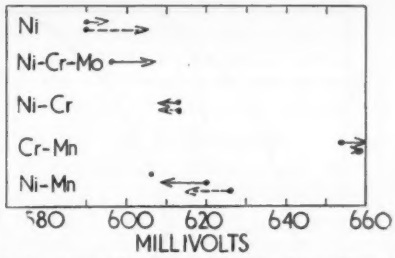
Measurements were made on some of the re-tempered specimens. The results for the nickel and nickel–manganese compositions are shown as broken curves in Figs. 26 (*a*) and 26 (*c*), and follow the impact curves. The curve for the nickel–chromium–molybdenum steel was also determined and was similar to

that for the nickel–manganese steel, except that it bulged upwards (*i.e.*, in a negative direction) to a maximum value of — 0·608 V., nearly the same as the minimum value of the nickel–manganese steel. The results for all compositions in the two heat-treatment conditions, (1) water-quenched from the tempering temperature (giving maximum toughness) and (2) heated for 1 day at 500° C. (giving minimum toughness) are given in Table VI.

Before discussing these the other results included in Table VI will be described. It is clear that the foregoing results on tough and brittle specimens were on transcrystalline and intercrystalline fractures respectively, and could therefore be influenced by the two factors, heat-treatment condition and character of fracture. To isolate the effect of the former on grain-boundary composition it was necessary to repeat all measurements on intercrystalline fractures. These were obtained for both heat-treatment conditions by breaking at liquid-air temperature. A Charpy machine was used to ensure rapid transfer from the liquid air to the machine. The extent to which intergranular fracture was realized has been discussed under "Fractographic Examination." The impact values are given in the right-hand side of Table V. All the specimens were very brittle and for all compositions, including the nickel steel, which, according to room-temperature tests was non-susceptible, heat-treatment (2) produced greater brittleness than heat-treatment (1). The potential measurements on these specimens are also included in Table VI.

The important feature is the last row giving the difference in potential between the water-quenched specimen and the comparison one tempered at 500° C. These differences are small but those for the chromium–manganese steel were checked and were reproducible. Since they are of different signs it again appears that composition or constitution changes are operative.

If temper-brittleness were due to a grain-boundary precipitate of some particular constituent, the potential of the intercrystalline fracture of an embrittled specimen should always approach a particular potential (that of the constituent) relative to the potential of the intercrystalline (liquid-air) fracture of a "tough" sample. The present results are plotted in Fig. 49 to facilitate this comparison. Among the



• Tough Condition (Tempered 635°C.)—Room-Temp. Fracture
>< Brittle Condition (Tempered 500°C.) ... Liq.-Air-Temp. Fracture

Fig. 49—Electrode potentials of fracture surfaces showing change induced by an embrittling heat-treatment

nickel – chromium – molybdenum, nickel – chromium, and nickel–manganese steels (and the non-susceptible nickel steel) this tendency is quite pronounced, the particular potential being about — 0·610 V., but the results for the chromium–manganese steel show that a common constituent does not also occur in this composition.

The largest difference between the intergranular fractures in the two heat-treatment conditions is for the nickel steel which is the least susceptible of those tested. The large difference suggests that not all grain-boundary (or cleavage-plane) composition changes are deleterious.

The zero difference for the liquid-air chromium–manganese fractures is taken to mean that factors other than composition—*e.g.*, strain—affect the potential, and that in this case the various factors are equal and opposite.

DISCUSSION

Temper-brittleness has often been ascribed to the formation, during an embrittling heat-treatment, of a grain-boundary precipitate, variously suggested to be a carbide, nitride, or phosphide. There are obvious difficulties in explaining the results of the three preceding sections by any kind of precipitate. Since the carbide particles coalesce substantially on long heating, considerable coalescence of a fine grain-boundary precipitate would be expected in the same time. In particular, a precipitate of nitride, suggested again recently by Holloman[5] seems less probable than

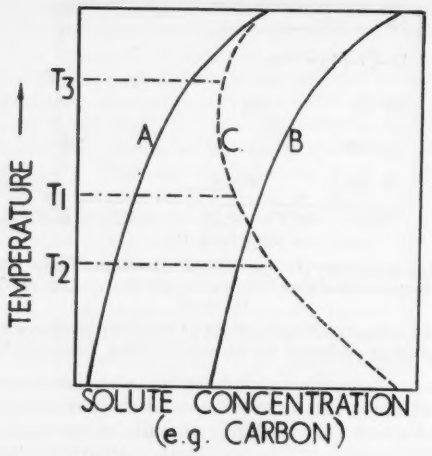
Table VI

ELECTRODE POTENTIALS OF FRACTURE SURFACES

Steel:	Ni		Ni–Cr–Mo		Ni–Cr		Cr–Mn		Ni–Mn	
Broken at:	r.t.*	l.a.†	r.t.	l.a.	r.t.	l.a.	r.t.	l.a.	r.t.	l.a.
(a) Heat-treatment 1	−590t‡	−590i§	−596t	...	−613t	−613i	−654t	−658i	−620t	−624i
(b) Heat-treatment 2	−594t	−614i	−608i	...	−609i	−608i	−659i	−658i	−610i	−616i
(a) − (b)	+4	+24	+12	...	−4	−5	+5	0	−10	−8

(Measured against a saturated calomel electrode in N/10 $FeCl_2$, millivolts)

* r.t. = room temperature
† l.a. = liquid-air temperature
‡ t = transcrystalline fracture
§ i = intercrystalline fracture



Curve A—Solubility in grain interior
Curve B—Solubility in grain boundary
Curve C—Concentration at grain boundary in equilibrium with curve A

Fig. 50—Diagram of suggested mechanism of intergranular embrittlement with and without intergranular precipitation

one of carbide in so far as nitrogen diffusion governs the rate of coalescence, since the rate of diffusion of nitrogen is known[6] to be greater than that of carbon in γ-iron (at not too elevated a temperature) and may therefore also be greater in α-iron at temperatures in the region of 500° C. No evidence of precipitate was seen on the fracture surfaces of embrittled specimens. To account for the grain-boundary (or cleavage-plane) electrode-potential change in the non-susceptible nickel steel caused by heat-treatment, a grain-boundary change must be assumed to occur in this steel also.

On the other hand it is possible to account for the observations by "equilibrium segregation,"[7] according to which solute atoms which differ in size from the solvent spaces they fill will tend to segregate, within a certain temperature range, to regions such as grain boundaries and, probably to a lesser extent, to internal surfaces of misfit, where, owing to lattice distortion, the solvent spaces vary in size, and some will therefore fit the solute atoms better than will perfect parts of the lattice. Consequently the distribution of solute atoms having minimum energy is one in which the concentration in distorted regions is higher than elsewhere. The degree of segregation should depend on the distortion a solute atom causes in perfect parts of the lattice. Since this distortion is high for carbon atoms dissolved in ferrite, carbon segregation to the grain boundaries should be appreciable and the boundaries will tend to behave like thin films of martensite. It is therefore to be expected that a heat-treatment which permits this segregation will cause marked grain-boundary embrittlement. Such embrittlement seems to occur in all ferritic steels at some temperature. It is suggested that alloy elements modify the properties of the grain-boundary "martensite"—*e.g.*, its thickness—and so govern the temperature at which brittleness manifests itself. It would be this zone which is revealed by the special etching reagents. Similar considerations apply to boundary segregation of other elements, *e.g.*, nitrogen.

Approximate estimation[7] shows that the ratio of grain-boundary concentration of solute to grain-interior concentration increases with decrease in temperature, although at low temperatures the attainment of equilibrium will be slow since it depends on diffusion. It is a consequence of the above picture that in systems where the solubility is low, such as carbon in ferrite, the solubility is greater in regions of atomic misfit, such as grain boundaries, than in undisturbed regions in the grain interior. Assuming the variation with temperature of the grain-boundary solubility to follow that of the grain-interior solubility, the situation depicted in Fig. 50 may occur. If the system is maintained at the temperature T_1, precipitation occurs in the grain interior, but not at the grain boundary, although a high concentration builds up there; this corresponds to the nickel–chromium steel (Figs. 39 and 40). If the system is maintained at the temperature T_2, grain-interior precipitation occurs, a high concentration gradually builds up at the boundaries as diffusion proceeds and, after it exceeds curve B, precipitation occurs there; this corresponds to the nickel–chromium–molybdenum steel (Figs. 41 and 42).

Ordinarily, grain boundaries are effectively stronger than grain interiors at moderate and low temperatures. Whether fracture occurs at grain boundaries, cleavage planes, or by irregular transcrystalline fracture, depends, on this hypothesis, on the relative embrittlement of the different parts of the crystal aggregate by segregation. This implies that the susceptible steels in the "tough" condition had already suffered some grain-boundary embrittlement, *i.e.*, the tempering temperature corresponded to T_3, Fig. 50, since at liquid-air temperature fracture occurred at the boundaries.

Segregation to grain-boundary and internal surfaces of misfit of each of the solute elements contained in these steels should occur, since the size of their atoms differs from that of iron atoms. Consequently, suitable heat-treatment should cause grain-boundary and cleavage-surface composition changes in non-susceptible as well as susceptible steels. Since the lattice distortion at boundaries, etc., is generally supposed to extend for only a few inter-atomic distances, the segregated layer would be expected to be correspondingly thin and difficult to etch. There appears to be no reason why fracture surfaces of "tough" and "brittle" specimens, arranged to be intergranular in both cases, should have a different appearance.

CONCLUSIONS

(1) Discrimination between tough and brittle samples of steels susceptible to temper-brittleness is shown to be possible by micro-examination, whether the brittleness is produced by slow cooling or by re-tempering. Grain boundaries, and sub-boundaries, which probably envelope different orientations within the parent austenite grain, are revealed in brittle samples by certain etching reagents. For general use the best reagents are probably ethereal solutions of picric acid containing CTAB or Zephiran chloride

(Nos. 7–9, Table I). None of the reagents discriminated significantly between retempered, slowly cooled, or rapidly cooled samples of the one non-susceptible steel examined.

(2) In notched-bar tests the room-temperature fractures of tough specimens were transcrystalline and of brittle ones intercrystalline.

(3) Electrode-potential measurements on fractures indicated that the composition of the grain-boundary zone varied with heat-treatment.

(4) It is suggested that temper-brittleness is due to segregation, without precipitation, of carbon atoms to the grain boundaries, which thus acquire properties similar to martensite.

Acknowledgments

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References

1. J. B. Cohen, A. Hurlich, and M. Jacobson : *Transactions of the American Society for Metals*, 1946, Preprint No. 17.
2. D. McLean and L. Northcott : *Journal of the Institute of Metals*, 1946, vol. 72, p. 583.
3. R. H. Greaves and J. A. Jones : *Journal of The Iron and Steel Institute*, 1920, No. II, p. 181 ; 1925, No. I, p. 231.
4. C. A. Zappfe : *Transactions of the American Society for Metals*, 1945, vol. 34, p. 71.
5. J. H. Holloman : *Transactions of the American Society for Metals*, 1946, vol. 36, p. 473.
6. F. Seitz : " The Physics of Metals," p. 180. New York, 1943 : McGraw-Hill.
7. Report in preparation.

A Theoretical Analysis of the Stresses and Strains in Extrusion and Piercing

By R. Hill, M.A. (Cantab.)

SYNOPSIS

The power consumption and distribution of stress and strain in the mechanical-working processes of extrusion and piercing are calculated from the equations of plastic flow developed by Hencky and Geiringer. The determination of the shape of the plastic region and the motion of individual elements is an essential part of the analysis, and distinguishes it from all earlier theories. The pressures of extrusion and piercing are evaluated for both square and conical dies over a wide range of reductions in area and frictional conditions. The deformation of a square grid scribed on a longitudinal section is calculated in the case of inverted extrusion with a 50% reduction.

Introduction

The present paper describes a theoretical analysis of the stresses and strains in the processes of extrusion and piercing. Early attempts to calculate the expenditure of work in these processes were based on the assumption that the deformation is a homogeneous compression. It is now generally appreciated that the work calculated in this way is an underestimate—frequently considerable—and that the actual distortion is far from uniform. The lack of uniformity is not merely the effect of friction. Homogeneous deformation is not possible, even when friction is absent, because of the constraint on the plastic flow exerted by the die or punch and the material bordering the plastic region. Various empirical corrections have been made to allow for the expenditure of " non useful " work, but no satisfactory theory has been developed. It is clear on general grounds that the theory must rest on a determination of the shape of the plastic region and the motion of the individual elements of the material. Both these features will be calculated in the theory to be described. Direct and inverted extrusion are considered for dies of any angle and any reduction of area. The particular piercing operation which is analysed is such that the metal to be worked is held in a rigid container and hollowed out by the action of a die or punch. Extrusion and piercing can be conveniently considered together since the theory is very much the same for both.

The analysis is based on the equations of plastic flow in the form established by Hencky[1] and Geiringer[2] for a state of plane strain. Strictly, the analysis will thus be valid only when the plastic flow occurs in parallel planes, so that the metal to be extruded or pierced is not a cylinder but a wide rectangular block. Such a simplification is as yet unavoidable : complete solutions for the axially symmetric operations are at present beyond reach.* Failing the full analysis for the extrusion or piercing of cylindrical billets, much can be learnt from the plane-strain solutions. We can, for example, expect the cylindrical and plane-strain operations to resemble each other in the general variation of the plastic region and the dead metal with the shape of the die and container, and with the lubrication employed. This expectation is confirmed by comparison of the plane-strain theory with data obtained from small-scale experiments with cylindrical billets. Again, the calculated distortion of a square grid scribed on a section of a split billet is broadly in agreement with observation. It is found further that

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* The general features of the axially symmetric problem in plasticity have been examined by R. Hill in a report to the Armament Research Department, Ministry of Supply, in 1946.

the calculated pressures of extrusion and piercing are roughly equal to those measured for cylindrical billets with the same reduction of *area*. This is, perhaps, a coincidence which could hardly have been foreseen. We can thereby immediately establish a correlation between calculated quantities for the plane-strain model and the corresponding quantities in the actual conditions of axial symmetry. This is particularly fortunate in practice, since it enables the stresses and the power consumption to be estimated for cases outside the range covered by known data.

THE BASIC EQUATIONS OF PLANE-STRAIN PLASTIC FLOW

For convenience of reference the equations of plastic flow under conditions of plane strain will be listed briefly. They are given in the forms due to Hencky (stress equations) and Geiringer (velocity equations), which express the variation of the stress and velocity components along the slip-lines. A detailed account has been given by Geiringer.[3] The only summary in English appears to be that by Hill, Lee, and Tupper.[4]

The slip-lines are, by definition, the two orthogonal families of curves whose tangents at any point are in the directions of maximum shearing stress. In annealed mild steel the slip-lines show up as the familiar Lüders' lines. The two families will be labelled α and β respectively; they are distinguished by the sense of the maximum shear stress, K, acting across them (Fig. 1). If the yield criterion of von Mises is adopted, K is constant and equal to $Y/\sqrt{3}$, where Y is the yield stress in uniaxial tension. In any given instance Y must be taken to be the yield stress corresponding to the mean temperature and rate of strain of the process. At the usual temperatures of extrusion the work-hardening is small and can be neglected in the theory. If the hardening is not negligible, some semi-empirical correction will have to be introduced; for most practical purposes it is sufficient to take Y to be the mean of the initial and final values of the yield stress.

The mean compressive stress p is, by definition, $-\frac{1}{2}(\sigma_1 + \sigma_2)$, where σ_1 and σ_2 are the principal stresses in the plane. All four sides of a small curvilinear element bounded by a pair of neighbouring slip-lines are thus under shear stresses K and normal compressive stresses p. The principal stresses are $-p \pm K$ in the plane and $-p$ normal to the planes of flow. Hencky's equations are then

$$\left.\begin{aligned} p + 2K\phi &= \text{constant along an } \alpha \text{ slip-line} \\ p - 2K\phi &= \text{constant along a } \beta \text{ slip-line} \end{aligned}\right\} \quad \ldots\ldots(1)$$

where ϕ is the *anticlockwise* angular orientation of a slip-line with respect to some fixed direction. The variation of p along a slip-line is thus directly related to the angle turned through by the slip-line. Hencky also proved the following geometrical theorem:

> The angle between two given slip-lines of one family, where they are cut by an arbitrary slip-line of the other family, is constant along their length.

This is an immediate consequence of equation (1), since the difference in p between two points can be calculated in terms of the variation in ϕ by proceeding along either of the two slip-line paths between the points. Hencky's theorem merely expresses the necessary fact that the difference, calculated in the two ways, is the same. Any two orthogonal families of curves possessing this geometrical property constitute the slip-lines of a plastic mass in quasi-static equilibrium under certain boundary conditions. Special families which obviously possess the property, and which occur frequently in this paper, are (i) two orthogonal sets of straight lines, representing a uniform stress distribution, and (ii) radii and concentric circular arcs, representing a possible distribution of stress round a point singularity. A third example is any set of non-intersecting straight line-segments and their orthogonal trajectories.

To calculate the paths of individual elements we need to introduce the "velocity" components u and v referred, at any point, to the directions of the α and β slip-lines respectively. Velocity is measured

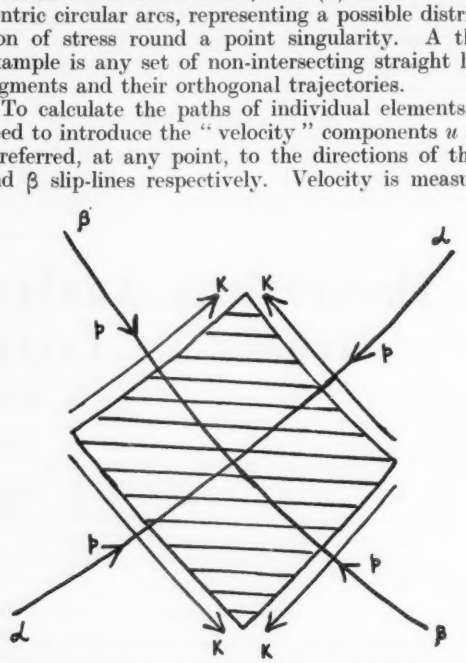

Fig. 1—Stresses on a small element bounded by slip-lines

not on a time scale, since the flow is considered to be quasi-static and inertia is neglected, but relatively to the prescribed motion of some part of the system. It will usually be most convenient to measure the velocity in terms of the motion of the die or punch, which can be taken to move with unit speed. The equations of Geiringer, analogous to those of Hencky, are

$$\left.\begin{aligned} du - vd\phi &= 0 \text{ along an } \alpha \text{ slip-line} \\ dv + ud\phi &= 0 \text{ along a } \beta \text{ slip-line} \end{aligned}\right\} \quad \ldots\ldots(2)$$

These are deduced from the experimental facts (i) that the plastic volume change is negligibly small, and (ii) that when elastic strains can be neglected, the directions of maximum shear-strain rate coincide with the directions of maximum shear stress. Elastic strains can be neglected in the present problems since the plastic strains are large and the plastic material is not entirely constrained by elastic material in which the displacements are small. In other words, material can be taken to be rigid when it is not undergoing plastic deformation. It can be shown that the boundary of the region where plastic flow is taking place must then be a slip-line, except where the plastic region adjoins a wall or die. Outside this region there

will usually be material which is stressed to the plastic limit, but is still rigid owing to the constraint of surrounding non-plastic material. This corresponds in fact to the region where elastic and plastic strains are comparable. In the present problems, though by no means in all others, this rigid part of the plastic region need not be determined. The diagrams show only the part of the plastic region where the strains are large compared with elastic strains. This should be remembered when comparing the results with experimental data. In principle the determination of the rigid part of the plastic region is straightforward, but in practice it would require considerable computation, possibly by relaxation methods. For convenience the region of large plastic strains will be loosely spoken of as the plastic region, and its boundary as the plastic boundary.

It is not usually possible to calculate the shape of the plastic region or the slip-line configuration by

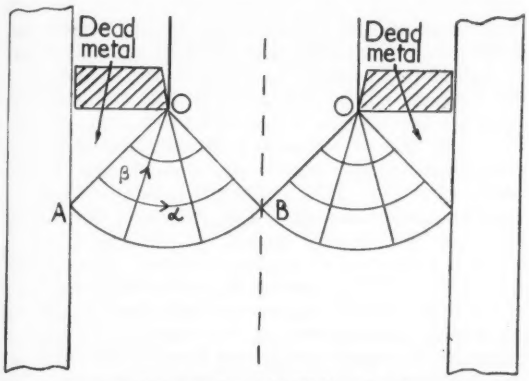

Fig. 2—Inverted extrusion with 50% reduction, showing slip-line field and plastic region

the use of equations (1) alone, even though there are two equations for the two unknowns p and ϕ. The crucial factor is the boundary conditions. Whenever the boundary conditions in the stresses are insufficient to determine the plastic region uniquely, it is necessary to satisfy also the velocity equations and the velocity boundary conditions. The physical problem will then be such that more velocity boundary conditions are given than would be needed to fix the velocity solution *if* the slip-line field were known. It is the satisfying of the "redundant" velocity boundary conditions which determines the unique slip-line field which actually solves the problem. It is of course obvious that the stress and velocity equations must be satisfied simultaneously in a problem where the external surfaces are changing during the flow, *e.g.*, in deep indentations. A little more consideration is needed in steady-motion problems (extrusion, rolling, drawing) where the configuration does not change with time, or in initial-motion problems (*e.g.*, shallow indentation, yielding of a notched bar) where the change of external surfaces can be neglected. In some of these two types of problems there are sufficient stress boundary conditions to allow the stresses and the plastic region to be uniquely determined; the velocity boundary conditions are then just sufficient for calculating the velocities. In others (for example, the present problems of extrusion and piercing) there are insufficient stress boundary conditions; a consideration of the velocity solution is therefore unavoidable. This distinction has not been appreciated by earlier workers. Recently, for instance, van Iterson[5] and Siebel[6] have suggested several possible slip-line fields in the case of extrusion; neither considered the associated velocity solution and so failed to decide which, if any, of their proposed slip-line fields was the correct one. As a matter of fact, none of them was, as we shall see.

INVERTED EXTRUSION WITH 50% REDUCTION

It is convenient for purposes of presentation to begin with a detailed description of the steady-state solution for inverted extrusion with a square die and 50% reduction in area.

It is not usually possible to build up a solution to a problem by a logical step-by-step process. The method is usually one of trial and error, in which the solution is finally seen in its entirety. For the same reason the solutions will be presented as a whole, and then shown to satisfy all the stress and velocity boundary conditions. In Fig. 2 OAB is one-half of the plastic region. The β slip-lines are radii through the die corner O, and the α slip-lines are concentric circular arcs. The dead metal in the corner is bounded by OA; it takes no part in the steady flow even though part of it may be stressed to the plastic limit. Inverted extrusion is distinguished from direct extrusion by the absence of friction between the container wall and the undeformed billet, since these do not move relatively to each other. It is therefore correct to take the slip-lines at A to make an angle of 45° with the wall. For reasons of symmetry they must also intersect the central axis at B at 45°.

The remaining boundary conditions which we must verify to be satisfied by this choice of the slip-line field are those concerning velocities. On OA the normal component of velocity must be zero; across AB and OB the normal components of velocity must be compatible with the rigid motions of the undeformed billet and extruded material respectively. There are no restrictions on the tangential velocity components along the plastic boundary. In fact there will often be a tangential discontinuity in velocity in moving across the plastic boundary. This implies a momentary infinite rate of shear, but this is permissible since work-hardening is neglected, and since the slip-line boundary is a direction of maximum shear-strain rate. The existence of the line-discontinuity of velocity is a consequence of neglecting elastic strains, and is the idealization of what is actually a narrow region of severe shear strain. When the hardening is appreciable, the transition from a region of small strains to one of large strains will be still more diffuse.

Let us suppose for convenience in description that the metal and container together move with unit speed towards the stationary die, so that the plastic region is fixed in space. Let θ be the angle between a radius from the corner and the axis; the sense of

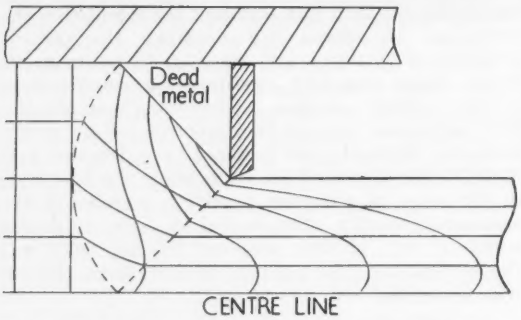

Fig. 3—Deformation of squared grid in inverted extrusion with 50% reduction. Broken line indicates boundary of plastic region

θ is taken such that θ is $+45°$ on OA and $-45°$ on OB. From equations (2) we see that the velocity component v is constant along each radius, and equal to $\cos\theta$ by the continuity condition across AB. The velocity component u is found by integrating from OA, where $u = 0$, along the α slip-lines. We have

$$u = 1/\sqrt{2} - \sin\theta\,;\ v = \cos\theta \quad \text{.....(3)}$$

Hence on OB, u is constant and equal to $\sqrt{2}$. This is compatible with the rigid motion of the extruded metal, the speed of extrusion being 2. This, of course, is to be expected from *a priori* considerations of incompressibility. All conditions on the plastic boundary have now been satisfied.

The stresses can be found from equations (1). From the second relation, p is seen to be constant along each radius, and hence, by considering the equilibrium of the extruded metal, is equal to K on OB. By integration of the first relation along α-lines, we find $p = K\ (1 + \pi)$ on OA. The total force on the die per unit width normal to the plane is $K(2 + \pi) \times$ die width (neglecting possible friction between the wall and the dead metal). The extrusion pressure, P, defined as extrusion force divided by the area of the original billet, is then

$$P = K(1 + \tfrac{\pi}{2}) = 1{\cdot}29 \times 2K \quad \text{.....(4)}$$

$2K$ is the compressive yield stress under conditions of plane strain. The analogous formula for a cylindrical billet, reduced in area by 50%, can be assumed to be $P = 1{\cdot}29Y$, where Y is the yield stress in uniaxial compression. The simple estimate of the extrusion pressure, based on the assumption of homogeneous deformation, would give $P = Y \log_e 2 = 0{\cdot}7Y$. This is a considerable underestimate. The expenditure of "non useful" work is in this instance about 45% of the whole.

The trajectory of a particular element which crosses AB $(r = a)$ when $\theta = \theta_0$ has the equation

$$\frac{1}{r}\frac{dr}{d\theta} = \frac{v}{u} = \frac{\cos\theta}{1/\sqrt{2} - \sin\theta},$$

and therefore

$$\frac{r}{a} = \frac{\left(1/\sqrt{2} - \sin\theta_0\right)}{\left(1/\sqrt{2} - \sin\theta\right)} \quad \text{.....(5)}$$

When $\theta_0 = \pi/4$, the element simply moves along AO with speed $1/\sqrt{2}$. The time taken to move along the trajectory (5) between two points lying on the radii θ_1 and θ_2 $(\theta_1 > \theta_2)$ is given by

$$t = \int_{\theta_2}^{\theta_1} \frac{r\,d\theta}{u} = a\left(1/\sqrt{2} - \sin\theta_0\right)\left[F(\theta_1) - F(\theta_2)\right],$$

where

$$F(\theta) = \frac{2\cos\theta}{1/\sqrt{2} - \sin\theta} - 4\coth^{-1}\left[(\sqrt{2} + 1)\tan(\tfrac{\pi}{4} - \tfrac{\theta}{2})\right] \quad \text{.....(6)}$$

From equations (5) and (6) it is easy to calculate the deformation of a square grid ruled on a cross-section of the billet. The result is shown in Fig. 3, and gives the position of the deformed grid at the moment when a transverse line is just about to become plastic. The axial lines of the grid in the extruded billet are straight and equally spaced at a distance half of that before extrusion. This is a simple consequence of the steady-state conditions. The deformed transverse lines are also equally spaced, at a distance apart which is twice that in the original grid. The general distortion, and in particular the severe dragging back of the surface layers, agrees well with observations on small-scale experiments (*see*, for example, the photographs in Pearson's well-known book[7]). The kink in the deformed grid near the central axis may be peculiar to the plane-strain problem : it does not seem to occur (in general) under conditions of axial symmetry where the hoop-strain is predominant near the axis.

When the bulk of the metal is at rest and the die is caused to move, it is only necessary to superimpose a unit velocity backwards to obtain the actual motion in space of the deforming metal. The stresses and the deformation are, of course, the same as before. It is easily seen that metal for which $\theta_0 > 0$ begins to move backwards in space towards the rear of the chamber when the plastic boundary AB first reaches it. Afterwards the metal reverses its direction of motion and flows towards the die orifice.

GENERAL INVERTED EXTRUSION THROUGH SQUARE DIES

When the reduction in area is less than 50%, the slip-line field for inverted extrusion with a square die has the form shown diagrammatically in Fig. 4. This is also the solution for direct extrusion with perfect lubrication. AOB is a region where the slip-lines are radii through O and concentric circular arcs. The dead metal has the shape of a right-angled isosceles triangle. Since there is negligible friction on the chamber wall the slip-lines must meet the wall at 45°. It can be shown that this condition uniquely determines the continuation $ABCD$ of the plastic

region outwards from AB.* It is the same slip-line field which would be obtained as the continuation from two orthogonal circular arcs of equal radii—in this case AB and its reflection in the wall. This continuation has to be calculated numerically by a small-arc process.† The region AOB is extended round the corner up to the slip-line OBD, meeting the central axis at D in 45°. The continuation $ABCD$ is then stopped at the slip-line CD through D.

The justification of this field, by considering the velocity boundary conditions, is as follows. Suppose, as in the last section, that the container and metal are together moved towards a stationary die. The normal components of velocity are known across the entry and exit plastic boundaries CD and OD from the speed of extrusion and the fact that the metal does not change its volume. The velocity solution can then be calculated (by a small-arc numerical process) throughout $OECD$ by using equation (2). The solution within AEC can be found using the boundary conditions on CE and CA, *viz.*, the known normal components of velocity across CE and the

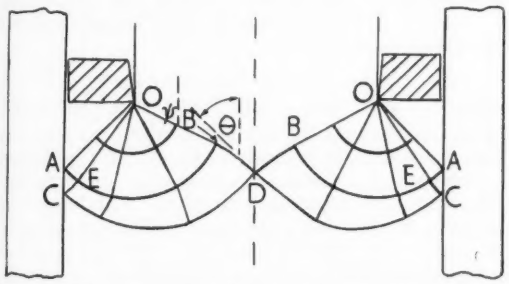

Fig. 4—Slip-lines and plastic region for inverted extrusion with a reduction of less than 50%

known zero component of velocity normal to AC. Finally the velocities within AOE can be calculated using the known components of velocity normal to AE and OE. The slip-line field will be correct if the calculated velocity component normal to the dead-metal boundary OA turns out to be zero. We can prove that this is so without carrying out the numerical calculations in detail—an extremely fortunate situation! In OAB the β slip-lines are straight and so, from equation (2), the velocity component v is constant on each radius. Now the component u is constant along OB. Hence, from equation (2) the component u is also constant on each radius, and in particular on OA. But since the solution has been built up using the speeds of entry and exit corresponding to zero volume change, it follows that there is no net outflow across OA. The velocity component normal to OA would therefore turn out to be zero. Notice that there are tangential velocity discontinuities across OD, CD, and OC.

Let θ be the angle between the tangent at any point on BD and the axis. Let ψ be the constant

* The proof depends on the properties of characteristics of hyperbolic partial differential equations.

† This has been described in a report to the Armament Research Department, Ministry of Supply, which it is hoped to publish shortly.

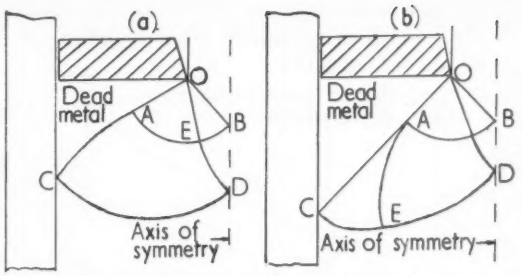

Fig. 5—Possible slip-line fields for inverted extrusion with a reduction of more than 50%

value of θ along OB. By using equation (1) and the condition for equilibrium of the extruded metal, it is easy to show that the extrusion pressure is

$$P = K\left(1 - \frac{d}{D}\right)\left(1 + \frac{\pi}{2} + 4\psi + \frac{2h}{d} - \frac{4\int \theta \sin\theta ds}{d}\right) \quad (7)$$

where D and d are the initial and final widths of the billet and h is the depth of D below O. The integral is to be taken along OBD. In Fig. 6 $P/2K$ is plotted as a function of the reduction in area ($1 - d/D$ in the plane-strain model). A limit is set to this solution as the reduction is decreased by the possibility that plastic flow may extend round the die corner O to the free surface of the extruded billet. This occurs when the mean die pressure is $2K(1 + \pi)$, and the extrusion pressure is $2K(1 - d/D)(1 + \pi)$. This corresponds to a reduction in area of approximately 8%. For still smaller reductions the theory indicates that the actual reduction in area is less than the nominal (provided the die is cut back sufficiently sharply), and that the metal passing through the die spreads out by *plastic* distortion behind the die. This spread can be calculated by a slight extension of the present theory. It would be interesting to know whether it has actually been observed.

Consider next a reduction of more than 50%. Two quite different solutions can be found in this case (Fig. 5). each of which satisfies all the stress and velocity boundary conditions on the plastic boundary. In Fig. 5 (*a*) the slip-lines in AOB are radii and circular arcs; OB meets the axis at 45°. $ABCD$ is the unique continuation from AB and its reflection in the central axis (not the wall, as in Fig. 4). In Fig. 5 (*b*), the slip-lines in OAB are radii and circular arcs; OB meets the axis at 45°. The dead metal is bounded by the straight line OAC, meeting the wall at 45°. $ABED$ is the continuation from AB and its reflection in the axis. Region AEC is defined uniquely by the slip-line AE and the condition that AC is an envelope of slip-lines of the same family. It can be shown by the method already outlined that both slip-line fields satisfy the velocity boundary conditions. (Note that the velocity solution must be commenced in $ACDE$ in (*a*), and in ACE in (*b*).) How, then, can we decide which is really the solution of the problem?

The answer is suggested by the following consideration. If the dead metal were replaced by a perfectly rough die of the same shape, no difficulty would arise: the solutions would then correspond to extrusion through different dies of the given shapes. This

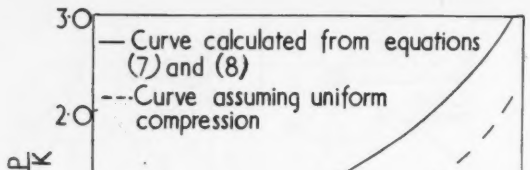

Fig. 6—Extrusion pressure in inverted extrusion through square die

remark suggests the probable explanation : the solutions correspond to different frictional conditions where the dead metal is in contact with the die and container wall. If the stresses could be calculated within the dead metal, it would presumably be found that the existence of a dead-metal region of a given shape requires the satisfying of certain necessary conditions by the friction called into play on the external surface of the dead metal. It is possible, therefore, that there are other slip-line fields (satisfying the stress and velocity conditions on the plastic boundary) corresponding to a range of frictional conditions on the dead metal. In view of the great experimental difficulty of measuring the friction with any precision under the actual conditions of extrusion, there seems no point in pursuing the matter further theoretically. However, experiments could easily be designed to see, in a general way, how the region of dead metal depends on the friction along the die and the container wall.

The difference in the extrusion pressures calculated for the two solutions is small. The pressures are, of course, equal for a reduction of 50% to the value in equation (4). For larger reductions the pressure for solution (*b*) is slightly the higher, but even for a reduction of 80% the difference by proportion is only 5%.* The extrusion pressure for solution (*a*) is given by a formula similar to that of equation (7) :

$$P = K\left(1 - d/D\right)\left(1 + \frac{\pi}{2} + 4\psi + \frac{2h}{D-d} - \frac{4\int\theta\sin\theta\,ds}{D-d}\right) \quad \ldots\ldots(8)$$

where h is the depth of C below O, and the integral is taken along OAC. It is interesting to notice that the mean die pressure for a fractional reduction r in solution (*a*) is the same as the mean die pressure for a reduction of $(1 - r)$ in the solution of Fig. 4. The extrusion pressure calculated from equation (8) is plotted in Fig. 6, together with that calculated from equation (7) when the reduction is less than 50%. Also shown for comparison is the extrusion pressure corresponding to homogeneous compression. The relative expenditure of non-useful work, not directly contributing to the reduction of area, is seen to be greatest when the reduction is small. This is analogous to what is found in wire-drawing and rolling. It should be noted that there is an upper limit to the reduction for which the solution of Fig. 5 (*a*) and equation (8) is valid. This limit corresponds to the value $\psi = 90°$. The solution for still larger reductions is not clear. There is little experimental data with which to compare Fig. 6, since the compressive yield stress is not usually measured. The general shape of the curve is, however, close to what is observed. The expenditure of non-useful work is also roughly the same as that found by Eisbein and Sachs.[8]

The deformation of a grid has not been calculated in the general case, since the computations would be rather laborious and the result can be expected to be qualitatively the same as in Fig. 3. It can be shown, by considering the distortion of a small element on the axis, that, when the reduction is less than 50%, the acute angle between the deformed transverse lines of a square network and the axis is $\cot^{-1}(D/d - 1)^2$. The kink is therefore less pronounced the smaller the reduction.

DIRECT EXTRUSION THROUGH SQUARE DIES

The slip-line field for unlubricated direct extrusion through a square die is shown in Fig. 7. It is assumed that the friction on the container wall is sufficiently high to cause local breakdown of the metal, so that the α slip-line intersects the wall at C at right-angles. An obvious modification can be made when other frictional conditions are more appropriate. A proviso similar to that in the last section must be made about the dependence of the dead-metal region on the friction along the die surface. However, the dead-metal region in Fig. 7 is very similar to that observed in small-scale experiments (*see* Pearson[7]).

The slip-lines in OAB are radii and circular arcs. OB meets the central axis in 45°. $ABCD$ is the continuation defined by AB and its reflection in the axis. This continuation is cut off at the slip-line OAC meeting the wall tangentially ; the angle AOB

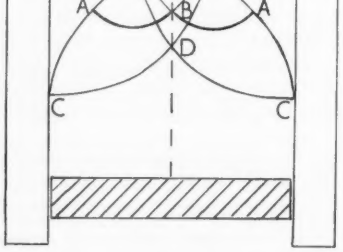

Fig. 7—Direct extrusion through square die with no lubricant

* The author is indebted to Mr. S. J. Tupper, Armament Research Department, for computing the extrusion pressure in solution (*b*).

thus depends on the magnitude of the reduction. This fixes the position of the entry boundary *CD*. The velocity boundary conditions can immediately be seen to be satisfied. There is now no tangential discontinuity on *CD*. As before, there is an upper limit to the reduction in area for which this type of solution holds, but there is no lower limit.

The extrusion pressure is given by equation (8) (the integral being evaluated along *OAC*), together with the addition of a term representing the friction between the wall and the remaining length of billet. The calculation has not been carried out ; it can easily be done when required. As the length of the billet left in the container becomes shorter, the extrusion pressure steadily decreases and reaches a minimum just before the completion of extrusion. A rapid rise follows this minimum. The minimum is found experimentally to be roughly equal to the steady-state pressure in inverted extrusion. There is, however, no reason why the two should be strictly equal since the dead-metal region is different. General considerations show that the minimum in the direct method should be somewhat greater than the steady pressure in the inverted method.

PIERCING WITH A FLAT PUNCH

When the problem is regarded as one of the plane strain, the only difference between the steady states of inverted extrusion with a square die and piercing with a flat punch and *smooth* container is that the positions of the central axis and the chamber wall are interchanged. The slip-line field for piercing is shown in Fig. 8 for a reduction in area of less than 50%. This should be compared with Fig. 4. It is necessary that the chamber wall should be smooth in order that the slip-lines may intersect it at 45°. A false head of dead metal, in the shape of a 90° angle wedge, becomes attached to the punch and remains there during the steady-state period. A certain minimum degree of friction on the punch is presumably necessary in order that the cap of dead metal may be retained. The same solution is also valid for a punch with any head-shape which can be covered by a false wedge-shaped cap of 90° angle, provided that the friction on the punch is adequate. In the extreme case of a punch whose head is itself a 90° angle wedge, the friction must be sufficient for

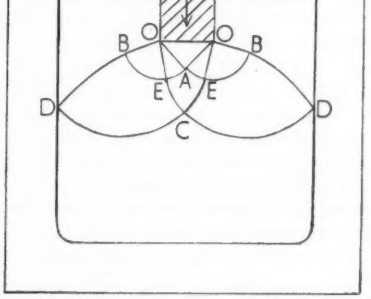

Fig. 8—Piercing with flat punch when the reduction is less than 50%. Chamber wall supposed smooth

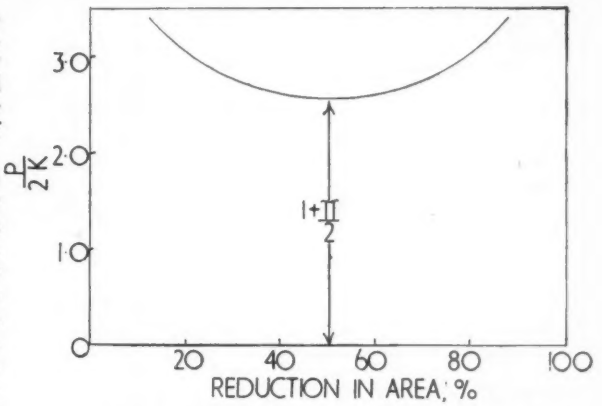

Fig. 9—Steady-state pressure for piercing with flat punch. Chamber wall supposed smooth

the face of the punch to be a slip-line. For reductions greater than 50%, two possible solutions can be found which are exactly analogous to those in Fig. 5. Each solution must imply certain frictional conditions along the punch face for its validity. When wall friction is present, these solutions must be modified accordingly.

When there is no wall friction, the pressure on the punch is clearly equal to (extrusion pressure)/(reduction in area), the extrusion pressure being that corresponding to the same reduction in inverted extrusion. The relation between the punch pressure, P, for the steady state and the reduction in area ((punch width)/(chamber width) in the plane strain model) has been calculated from the data in Fig. 6 and is shown in Fig. 9. The pressure has a minimum value of $2K(1 + \pi/2)$ for a 50% reduction, and the curve (in the range of validity of the solutions) is symmetrical about this point. Such a flat minimum was obtained by Siebel and Fangmeier[9] in experiments on the piercing of lead billets with cut-back flat punches. They found also that the pressure rose rapidly from the beginning of piercing towards the steady-state value, the rise being most rapid for large reductions in area. The steady state persisted until the punch was about half a calibre from the base of the chamber, when there was a rapid rise in the pressure needed to continue piercing. In the present solution the punch pressure needed to begin piercing would be $2K(1 + \pi/2)$ for reductions less than 50% (just as in Prandtl's solution for the indentation of an infinite half-plane) ; for reductions greater than 50%, piercing would not begin until the steady-state pressure was applied. This is in broad agreement with the results of Siebel and of Fangmeier, if allowance is made for the rounding of the pressure-penetration curves due to elastic strains and work-hardening. When the reduction is very small, the solution of Fig. 8 ceases to apply for the reason explained in the section on "General Inverted Extrusion through Square Dies" and also because it is no longer a good approximation to neglect the elastic compressibility of the material. As the reduction is decreased, the steady-state pressure can be expected to approach the limit corresponding

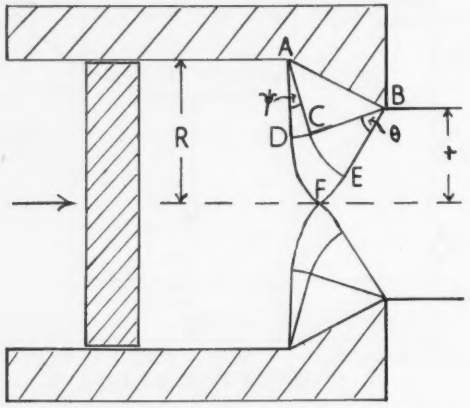

Fig. 10—Direct extrusion through wedge-shaped die with perfect lubrication

to the maximum pressure observed in deep punching into an infinite medium (Bishop, Hill, and Mott[10]). This is about $3{\cdot}5 \times 2K$ for a non-hardening material, the exact value depending on the elastic constants. It is not clear what the limiting pressure should be at the other extreme as the reduction is indefinitely increased.

EXTRUSION THROUGH WEDGE-SHAPED DIES

For simplicity it will be supposed that the chamber wall and the die are both free from friction, so that the slip-lines meet them at 45°. When friction is present, the solution can easily be modified by taking the slip-lines to meet the wall and die at the appropriate angle. The slip-line field for a certain range of reductions is shown in Fig. 10. There is now no dead-metal region. Adjacent to the die is a field ABC where the slip-lines are orthogonal straight lines; bounding this are two regions ADC and BEC where the slip-lines are circular arcs and radii from the corners; the remaining part $DCEF$ of the plastic region is the continuation from the two extreme circular arcs, and is taken up to the point where the slip-lines meet the axis in 45°. The whole configuration is determined entirely by the geometry of the container and die. This slip-line field can be shown to satisfy the velocity boundary conditions by the method shown above. The solution must be begun in $DCEF$ by using the known components of velocity normal to the entry and exit boundaries.

It is easily seen from the geometrical property of slip-lines, mentioned previously, that the angles $CBE = \theta$ and $CAD = \psi$ satisfy the relation

$$\theta - \psi = \alpha \qquad \text{.....(9)}$$

where α is the acute angle between the die face and the line of the wall. For a given die angle, θ and ψ decrease as the reduction of area increases. From simple geometry it can be shown that $\theta = \alpha$ and $\psi = 0$ for a reduction

$$1 - \frac{r}{R} = \frac{2 \sin \alpha}{1 + 2 \sin \alpha} \qquad \text{.....(10)}$$

For greater reductions than this another slip-line field becomes valid. At the other extreme, as the reduction is decreased, ψ ultimately becomes equal to $\pi/2 - \alpha$, and θ to $\pi/2$. For reductions less than this critical value, another slip-line field is required. The solutions outside the range covered by the slip-line field of Fig. 10 will not be described here.

It is interesting to notice that the present slip-line field is the same as that found for the plane-strain problem of wire-drawing.* The stresses in the plastic region in extrusion differ from those in wire-drawing only by the addition of a hydrostatic pressure numerically equal to the mean tensile stress applied to the wire (the back-pull being zero). The stresses in the elastic region do not differ simply by this hydrostatic pressure, so that strictly the plastic regions would be different in a full solution. It seems likely, however, that they would differ only in regard to the extent of that part of the plastic region where plastic and elastic strains are comparable. This part, as explained in the section on "The Basic Equations of Plane-Strain Plastic Flow," lies outside the calculated region of large strains and may be disregarded in the present problems. The numerical results obtained by Hill and Tupper for wire-drawing have accordingly been adapted in the way explained.

Some typical values of the extrusion pressure and the pressure on the die (which is uniform for this range of reductions) are given in Table I. The die pressure in extrusion is $R/r \times$ (die pressure in drawing), and the extrusion pressure is equal to the mean tension in drawing.

The relative expenditure of non-useful work is, for a given angle, greatest when the reduction is small (*cf.* the dotted curve in Fig. 6). It will be seen also that the pressure on the die increases greatly as the reduction is decreased. In fact, for sufficiently small angles and reductions, the theory indicates that the pressure rises to a value sufficient to cause plastic flow right round the die corner and out to the free surface. This can be thought of as if the die were an indenter being pressed into the material. The free surface becomes plastic for a die pressure

$$2K\left(1 + \pi/2 + \alpha\right) \qquad \text{.....(11)}$$

For example, when $\alpha = 5°$, this critical pressure is reached when the reduction has been lowered to about 1·8%. For still smaller reductions the theoretical implication is that the actual reduction is less than the nominal, due not merely to elastic recovery but to plastic flow round the die corner. It is furthermore implied that in the extreme case of complete recovery the bulk of the metal passes through the die undeformed, plastic distortion occurring only near the surface. However, the theory may cease to be valid for actual materials at such small reductions since the influence of elastic compressibility may become important. It may then not be a good approximation to treat the metal as rigid up to the yield point. It would be interesting to have experimental data bearing on the suggestion that plastic recovery may occur for very small reductions, and that only the surface layers of the metal may then be worked.

* R. Hill and S. J. Tupper, Paper for the Armament Research Department, to be published shortly.

Table I

VALUES FOR EXTRUSION PRESSURE AND PRESSURE ON DIE

$\alpha°$	$\psi°$	Reduction in Area, %	Die Pressure / $2K$	Extrusion Pressure / $2K$
10	0	25·8	1·18	0·303
	10	19·7	1·23	0·242
	20	15·2	1·36	0·206
	30	11·8	1·54	0·181
	40	9·2	1·75	0·160
	50	7·1	1·99	0·141
	60	5·5	2·25	0·123
20	0	40·6	1·35	0·548
	10	31·9	1·40	0·449
	20	25·2	1·53	0·388
	30	19·9	1·72	0·343
	40	15·5	1·95	0·302
	50	12·1	2·19	0·266
30	0	50·0	1·53	0·762
	10	40·1	1·59	0·635
	20	32·0	1·72	0·551
	30	25·4	1·91	0·486
	40	20·0	2·14	0·427
	50	15·6	2·39	0·372

The influence of friction in extrusion through conical dies is also analogous to its influence in wire drawing. For a given reduction there is an optimum die angle for which the power consumption is least. The optimum angle increases with increasing friction and with increasing reduction.

Acknowledgment

The author is indebted to the Chief Scientific Officer, Ministry of Supply, for permission to publish the paper.

The substance of this paper is contained in a report for the Armament Research Department, Ministry of Supply, written in 1945. A brief account of the work appeared in the *Journal of The Iron and Steel Institute* in August, 1947.

References

1. H. HENCKY : *Zeitschrift für angewandte Mathematik und Mechanik*, 1923, vol. 3, p. 241.
2. H. GEIRINGER : *Proceedings of the Third International Congress for Applied Mechanics*, vol. 2 : Stockholm, 1930.
3. H. GEIRINGER : *Mémorial des Sciences Mathématiques*, 1937, Fascicule 86.
4. R. HILL, E. H. LEE, and S. J. TUPPER : *Proceedings of the Royal Society, Series* A, 1947, vol. 188, p. 273.
5. I. F. K. VAN ITERSON : " Plasticiteitsleer." Holland, 1945.
6. E. SIEBEL : *Journal of The Iron and Steel Institute*, 1947, Apr., p. 526.
7. C. E. PEARSON : " The Extrusion of Metals." London, 1944 : Chapman and Hall.
8. W. EISBEIN and G. SACHS : *Mitteilungen der deutschen Materialprüfungsanstalten*, 1931, vol. 16, p. 67.
9. E. SIEBEL and E. FANGMEIER : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1931, vol. 13, p. 28.
10. R. F. BISHOP, R. HILL, and N. F. MOTT : *Proceedings of the Physical Society*, 1945, vol. 57, p. 147.
11. R. HILL : *Journal of The Iron and Steel Institute*, 1947, Aug., pp. 513–517.

The Study of Segregations and Inclusions in Steel by Micro-Radiography

By W. Betteridge, B.Sc., Ph.D., F.Inst.P., and R. S. Sharpe, B.Sc., L.I.M.

SYNOPSIS

The technique of micro-radiography is described in detail, including a simple mechanical method for the preparation of the necessary thin samples. Tables of linear absorption coefficients for different characteristic radiations are included to facilitate the identification of different segregates and inclusions.

Examples of the application of micro-radiography to the study of steels are described. It is shown that the overheating of steels does not produce segregation of the metallic alloying elements towards or away from the grain boundaries of the austenitic structure. Sharply defined segregates rich in manganese are shown to be a very common feature in many steels, and it is suggested that this phenomenon is worthy of a detailed examination.

Introduction

RADIOGRAPHY as normally used serves to reveal irregularities in X-ray absorption caused by defects such as cavities or sand inclusions, although in special cases the distribution of separate metallic phases can be shown. A typical example of the latter is found in copper–lead bearings where the lead is so much more absorbent than the copper that it appears on the radiograph as white patches clearly visible to the naked eye. In general, however, the structure of an alloy is so fine that in normal sections it may be said to be homogeneous and of uniform absorption, so that no structure is revealed. But if a very thin section of an alloy is prepared, comparable in thickness to the size of the particles of different phases in the alloy, and a radiograph taken with radiation for which the absorption coefficients of the various phases are markedly different, the distribution

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of the phases can be clearly shown when the radiograph is sufficiently magnified. This technique is known as micro-radiography and its application to the study of metals has been developed only within the last few years, although it was used with low magnifications as early as 1898 by Heycock and Neville[1] in the study of dendritic structures in slowly cooled binary alloys. Apart from work with biological specimens dating from Goby[2] in 1913, the method does not appear to have been used again until it was applied by Fournier,[3] who used the technique involving low tube voltages to produce long-wavelength X-rays, giving high absorption differences in the sample and necessitating evacuation of the path of the rays to reduce air absorption; he showed the type of radiograph obtained with aluminium alloys and copper–lead alloys, in which the relative distribution of the light and heavy elements was revealed at magnifications of about 100 diameters. The method was further improved by Trillat,[4] who referred to the use of characteristic radiations from a crystallographic X-ray tube chosen in relation to the composition of the sample so as to accentuate the differential absorption, in which case evacuation of the path of the rays became unnecessary. Trillat, however, apparently did not appreciate the extreme importance of the wavelength of the characteristic radiation in relation to the absorption edges of the constituents of the sample, for although he examined various steels, he stated that he found it impossible by this method to reveal elements such as vanadium, chromium, manganese, cobalt, and nickel present in iron, on account of the similarity in atomic numbers. He succeeded only in revealing the distribution of tungsten in a 3–4% tungsten steel. Clark and his co-workers[5–7] expounded the technique of using the characteristic radiation from a range of targets to reveal the distribution of individual elements by exposures with radiations whose wavelengths are above and below the critical absorption edges, and showed that in order to obtain maximum contrast between any two elements the radiation should be chosen so that the difference between the linear absorption coefficients is a maximum. Examples of the use of this method in relation to various non-ferrous metals were given, and although micro-radiographs of a few steel specimens were shown, these dealt with the simple cases of the distribution of lead, inclusions, and graphite. Later papers by Maddigan[8] and by Maddigan and Zimmerman[9] gave further examples of the micro-radiography of non-ferrous metals, but no results appear to have been published which cover any systematic work on steels.

In the present paper the results which have so far been obtained in the examination of steels are described as it is felt that they will be of some interest, particularly in the study of segregation.

TECHNIQUE

Preparation of Sample

Although for light alloys a sample with a thickness of about 0·005 in. is found to be generally suitable, it is most convenient, on account of their higher absorption, to reduce the sample thickness of steels to about 0·001–0·002 in. The area required is normally about $\frac{1}{4} \times \frac{1}{4}$ in., but much smaller areas could be dealt with if the condition of the material made it necessary. The thin slips were originally prepared by cutting a slab about $\frac{1}{16}$ in. thick from the material to be examined, fixing this to a flat metal holder with wax, and rubbing down by hand each face in turn on emery paper until the required thickness was obtained. It was found, however, that apart from being a tedious operation with hard steel, it was difficult by this method to keep the thickness sufficiently constant to prevent wide variations in density in the final radiograph, and impracticable to ensure preservation of the original edges. A simple mechanical device was therefore developed which enabled samples

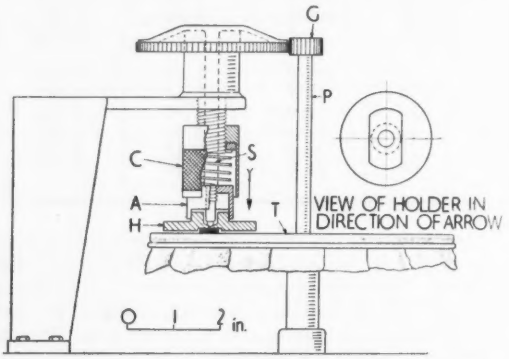

Fig. 1—Mechanical device for obtaining uniform micro-radiograph samples

uniform in thickness over the whole of the original area to be obtained quickly and with little effort. It consisted of an attachment to an ordinary metallurgical polishing wheel and is shown in Fig. 1. The shaft *P* was threaded into the centre of the wheel and carried at its top a small gear *G* which drove the larger gear attached to the shaft *S* with a reduction of 4 to 1. The shaft *S* carried at its lower end a dog *A* which fitted loosely about the sample holder *H* and rotated it. The end of the shaft *S* was rounded, and fitted into a recess in the specimen holder so that it pressed very closely behind the face carrying the specimen, and so minimized any tendency of the holder to rock under the influence of the frictional force of the rotating wheel against the sample. The downward pressure of the sample on the wheel was supplied by a spring and could be varied between about 1 and 2 lb. by adjustment of the collar *C* which was screwed on to the main mounting bracket. Two specimen holders were required, the first having a recess in its face with a depth of about 0·020 in. and the second having a similar recess 0·002 in. deep. A slice about $\frac{1}{16}$ in. thick cut from the material to be examined was fixed into the deeper recess with wax (Apiezon Wax W was found to be suitable); the holder was placed in position on the wheel, which was covered with a sheet of grade 1F emery paper, and the machine operated at about 240 r.p.m. Faster speeds generated sufficient heat to soften the wax and loosen the sample; hence by mounting in this

way, overheating of the sample was impossible. The emery paper was lubricated with paraffin. By this means the sample was ground down (at a rate of approximately 0·001 in./min. for a hard steel) until it was flush with the main surface of the specimen holder. The sample was then lightly polished by hand on finer emery to remove the deeper scratches on the ground face, removed from the first holder, and mounted in the reversed position in the second holder. Grinding on the machine was again carried out until the sample was flush with the face of this holder and after a final light polish it was detached, and then washed in a solvent to remove the traces of wax. For comparative microscopic examination it was found advisable for the sample to be finished to the requisite high polish before removing from the second holder, but the radiographic examination was always carried out before the microscopic, as etching produces local variations in the thickness of the sample which can lead to a spurious interpretation, by introducing another variable. All samples were stored in a desiccator, as atmospheric corrosion was found to give sufficient attack to be visible radiographically although not to the naked eye.

Camera

The function of the camera is merely to hold the sample and the sensitive emulsion in contact at a suitable distance from the target of the X-ray tube. It consisted of a brass plate $\frac{1}{8}$ in. thick with a central hole $\frac{1}{4}$ in. in dia., across which the sample was supported ; it was found convenient to cement the sample across a somewhat smaller hole in a sheet of card which fitted loosely into the camera body. To study a region adjacent to the edge of a sample, X-ray halation can be minimized by mounting the sample on to a piece of stripped X-ray film base and fixing into the camera so that the film is interposed between the X-ray tube and the sample. There is no loss of contrast and the film base appears quite structureless. The sensitive plate, which was cut to about 1 in. square, was held against the sample by a screwed back plate, with no black paper or other protection between the sample and the emulsion. The camera was hung from a rod clamped to the head of the X-ray tube, and its distance from the target was adjustable by sliding along the rod ; a distance of about 3 in. was found to be generally most convenient, the images obtained being quite sharp and the exposure times not too long.

Choice of Radiation

A Metropolitan-Vickers Raymax X-ray diffraction unit was used with a wide range of target materials for the selection of the most suitable radiation. In order to obtain the maximum contrast between any two constituents of an alloy the radiation should be chosen so that the difference between the two linear absorption coefficients is as great as possible, and this condition has been adequately described by Clark and Gross.[7] To help in the selection of the best radiation, the values of the linear absorption coefficients for different elements and a range of characteristic radiations are given in Table I. In order to reveal the segregation of any element in steel the radiation should be chosen so that the absorption coefficient of that element is as widely different as possible from that of iron ; for the commoner alloying elements with atomic numbers near to that of iron this implies that the wavelength of the radiation must be between the absorption edge of the particular element and that of iron.

When dealing with the detection and identification of metallic segregations, the values given in Table I for the absorption coefficients of the individual metals are all that is necessary, although it must be borne in mind that two alloying elements may segregate together or form an intermetallic compound and thus give an additive effect. For non-metallic compounds the effect of the lighter element becomes of great importance and the absorption coefficient of the compound needs to be calculated. In general the non-metallic element is present in sufficient quantity to make the absorption in the inclusion always less than that in the surrounding steel, so that the image of the inclusion is dark on a lighter background ; and there is no possibility of identifying its constituents by the choice of suitable radiations. Nevertheless the linear absorption coefficients of a number of typical inclusions have been calculated and are given in Table II.

The figures given in Tables I and II apply, of course, only to the monochromatic Kα radiations, while the radiation emitted from the X-ray tube includes also the Kβ component and the white radiation background. In order to minimize the white radiation the X-ray set was generally operated at about 17 kV. and 20 mA. tube current. Higher voltages would introduce a greater proportion of shorter-wavelength white radiation which would penetrate the sample with little absorption and produce general blackening with marked reduction in contrast. The conditions are different from those applicable to the use of the tube for diffraction work, for in the latter case the more penetrating white radiation produces less scattered radiation, which is the cause of background fogging, than the softer rays, and the increased characteristic emission at the higher voltages is required to reduce exposure times. Maddigan[8] has dealt with the correct choice of tube voltage to give maximum contrast, and recommends a voltage such that the peak of the white radiation emission curve gives a high differential absorption between the two phases which it is required to separate. It has, however, been found more convenient in the present work to use a constant voltage so that any change in appearance of a radiograph with change of target material could, without ambiguity, be related to the change of the characteristic rays, the white radiation remaining unchanged.

It appears that there is some advantage to be gained by the use of curved crystal monochromators, which will isolate any required characteristic radiation from the background and give a beam of sufficient area and intensity for radiography. Accurate interpretation of absorption differences would then be possible.

Filters to absorb the Kβ component and the white radiation immediately on the shorter-wavelength side of the required Kα component were considered, but were not used for two reasons. First, although they

would preferentially absorb the white radiation close to the Kα wavelength, they would transmit the radiation of shortest wavelength more readily than the monochromatic radiation ; and second, it was not found possible to obtain suitable foils which were quite structureless when radiographed, and so spurious images were obtained using these low tube focus-to-specimen distances.

Sensitive Material, Exposure, and Processing

In order that the radiograph obtained shall be capable of sufficient magnification without loss of detail, an extremely fine-grained emulsion is required and the only one available in this country which is suitable is the Kodak Maximum Resolution plate. Ilford High Resolution plates have been tried and were found only to be suitable for magnifications up to about 25 times, but their added speed might make them of value when higher magnification is not required. The Maximum Resolution plate can be magnified 200 times with little sign of grain and up to 500 times without it becoming unduly disturbing. But to obtain these favourable results it is necessary that the exposure should be adequate and the development not forced. The procedure adopted has been to standardize the development conditions ; all plates have been processed in the recommended Kodak developer D-178 for 1½ min. at 18° C., the exposure being adjusted to give the required density. In general about three trials were required before the correct exposure was obtained for any sample, and since this is critically dependent on specimen thickness, and also on the radiation used, standard times cannot be given ; however, with the conditions stated and a sample of steel 0·002 in. thick, the exposure was usually about 15 min. with copper radiation or 4 min. with cobalt radiation, these radiations being on either side of the K absorption edge for iron. After completion of development the plate was placed in an acetic acid stop bath, and then fixed in the usual manner. It was washed in running water for 15 min. and, in order to hasten drying and prevent collection of dust on the wet emulsion, soaked in methylated spirit for 5 min. and finally in pure alcohol for 5 min. As soon as the residual alcohol on the plate had evaporated, the emulsion was permanently protected by a cover glass cemented in position with Canada balsam in the conventional manner. It was found that the colour of the final image was a good guide to the quality of the processing ; a green tinge indicated good conditions with a fine grain-size, but with over-development and coarsening of the grain the colour tended towards a salmon pink.

The radiographs were normally viewed with trans-

Table I

LINEAR ABSORPTION COEFFICIENTS FOR Kα RADIATION

Absorber	Target Material										
	Ag	Pd*	Rh	Mo	Zn*	Cu	Ni	Co*	Fe	Mn*	Cr
Mg	3·9	4·5	5·1	7·6	60	70·5	85·1	105	131	162	208
Al	7·4	8·1	9·7	14·3	107	131	157	200	250	315	402
Si	8·0	9·8	10·5	15·6	115	140	176	216	270	345	446
S	10·5	12·0	13·5	20·5	150	186	227	285	357	448	557
Ca	14·8	16·7	19·6	30·3	225	263	321	395	485	610	777
Ti	52·2	60	69·9	105	750	902	1090	1350	1670	2100	2665
V	80·1	92	106	159	1150	1360	1650	2050	2540	3200	465
Cr	113	127	147	219	1550	1860	2270	2800	3520	485	646
Mn	130	146	169	250	1750	2120	2600	3550	475	590	742
Fe	157	177	203	301	2150	2550	3120	470	573	720	903
Co	191	215	246	365	2600	3100	477	570	707	870	1100
Ni	222	252	288	422	3600	438	543	650	828	1020	1290
Cu	236	265	303	443	425	470	580	720	882	1080	1370
Zn	201	233	269	391	350	421	514	620	780	970	1205
Mo	722	825	936	207	1400	1675	2010	2450	3050	3700	4485
Ru	$993\alpha_1$	172	191	291	1900	2300	2750	3400	4190	5050	6070
	$151\alpha_2$										
Rh	163	184	206	314	2000	2460	2980	3700	4480	5400	6480
Pd	166	188	212	321	2050	2490	3050	3750	4520	5450	6550
Ag	155	176	200	300	1950	2340	2900	3470	4220	5100	6140
Cd	134	152	174	258	1750	2020	2500	3000	3600	4400	5250
Sn	127	145	167	242	1650	1930	2345	2800	3330	4100	4960
Sb	124	142	164	236	1620	1900	2290	2770	3220	4020	4860
Te	119	136	156	225	1530	1800	2160	2570	3040	3800	4630
W	1050	1205	1360	2030	2650	3290	4025	5000	6160	7370	8780
Os	1330	1520	1730	2560	3500	4220	5130	6450	7850	9300	10,900
Ir	1390	1585	1810	2670	3600	4390	5365	6720	8200	9680	11,300
Pt	1380	1570	1800	2640	3550	4395	5320	6650	8060	9500	11,100
Au	1290	1475	1680	2470	3300	4130	5015	6220	7520	8920	10,400
Pb	844	965	1090	1600	2200	2730	3330	4100	4870	5750	6635
Bi	765	870	984	1420	2100	2480	3040	3720	4390	5170	6000

The bold lines indicate the position of the K absorption edge.
Values of μ/ρ taken from " Internationale Tabellen zur Bestimmung von Kristallstrukturen," 1935, vol. II, Bornträger.
*** For these radiations the coefficients are interpolated from the others, and are less accurate, particularly in the region of the absorption discontinuities.**

mitted light restricted by a small diaphragm so that only the darkened area of the plate was illuminated, otherwise considerable loss of contrast occurred because of halation. For photographic recording of the enlarged image a Vickers projection microscope was used, the radiograph being illuminated in a similar manner.

RESULTS OBTAINED IN THE EXAMINATION OF STEELS

Overheated Steels

Several recent publications have dealt with the problem of overheating of steels, and although no completely satisfactory explanation for the weakening of the boundaries of the enlarged austenitic grains has been established,[10] there seems little doubt that the observed change must be due to some change in composition at these boundaries, either diffusion of a non-metallic element to the boundaries, or segregation of the alloying elements at or away from the boundaries. In the former case the amount of non-metallic element would be very small and hence the possibility of its detection by micro-radiography would be negligible, but in the latter case the change in composition could be expected to be shown clearly and its character determined by radiography with suitably chosen radiations.

In such a search for unknown segregations it is generally sufficient to take two radiographs with radiations whose wavelengths are immediately above and immediately below the absorption edge of the main constituent—in the present case, iron. This will ensure that with at least one of the two radiations a marked difference exists between the absorption coefficient of iron and that of any other element. Further radiographs with critically chosen radiations would be required to identify the segregated element when it had been thus detected. For iron, the absorption edge occurs at a wavelength between those of the characteristic radiations of nickel and of cobalt; so that successive radiographs with these two radiations, or those of nearby elements, are all that are necessary in a search for suspected segregations.

Overheating is readily produced in nickel–chromium steels by heating to temperatures in the range 1250–1400° C., and a suitable sample for the investigation of possible segregation was prepared from a rolled bar of steel to British Aircraft Specification S82 by heating in an electric muffle furnace to 1400° C. for 30 min. The thin slip was prepared for both radiographic and micrographic examination, and reference marks were scratched on the surface so that identical areas could be compared. Micro-radiographs were prepared with the radiations from targets of copper and cobalt whose wavelengths are respectively below and above the absorption edge for iron. In neither case was any segregation observed, although subsequent etching of the sample in the nitro-sulphuric acid reagent recommended by Austin[11] clearly revealed the enlarged austenitic grain boundaries.

As an additional check on this failure to detect any metallic segregation associated with overheating, samples were cut from overheated forgings in the nickel–chromium air-hardening steel to specification S28. They were again prepared for correlated micrographic and radiographic examination and, as before, no segregation corresponding to the pattern of the enlarged grain was detected. Figure 2 shows the pattern revealed by the nitro-sulphuric acid etch. The micro-radiograph taken with cobalt radiation, however, revealed longitudinal segregations with a higher absorption than the background, and these are shown in Fig. 3. It is to be noticed that the positions of the heavy etching pits in Fig. 2 coincide with positions of the segregations revealed by the micro-radiograph, although, since every streak of segregated material does not break out into the surface, the pits are less numerous and not so lengthy.

Table II

LINEAR ABSORPTION COEFFICIENTS FOR Kα RADIATION

Absorber	Target Material							
	Mo	Zn	Cu	Ni	Co	Fe	Mn	Cr
Fe	301	2150	2550	3120	470	573	720	903
FeS	130	940	1100	1345	410	505	635	795
MnS	100	735	835	1070	1445	425	535	670
Al_2O_3	5	100	120	145	180	225	285	360
FeO	180	1290	1530	1880	310	380	470	590
Fe_3O_4	145	1050	1240	1530	255	310	390	490
Fe_2O_3	145	1025	1230	1480	250	310	390	485
MnO	145	1020	1230	1510	2060	300	375	480
SiO_2	10	65	80	100	125	155	175	255
$2FeO.SiO_2$	100	700	825	1020	225	280	350	445
$FeO.SiO_2$	65	470	555	680	190	235	295	375
$2MnO.SiO_2$	75	550	665	810	1110	235	295	370
$MnO.SiO_2$	55	405	490	610	820	220	275	355
Fe_3P	235	1730	2040	2490	495	600	750	945
TiO_2	60	445	545	650	800	995	1255	1595
$CaO.Fe_2O_3$	115	815	1120	1180	400	490	610	780
$2CaO.Fe_2O_3$	105	745	885	1080	500	610	765	980
TiN	100	725	865	1050	1300	1600	2020	2565
ZrN	105	755	885	1080	1320	1610	2000	2440
VN	115	845	980	1195	1485	1840	2330	360

The segregations were completely invisible on the unetched surface of the sample and remained invisible after normal etching in dilute picric or nitric acids.

In order to identify the segregating element, further radiographs were prepared with different radiations before the etching and micrographic examination just described. The segregations were only visible with the cobalt radiation, being then more absorptive than the matrix, and disappeared with the adjacent radiations from nickel and iron targets. Only manganese-rich areas could account for such properties. From a study of the linear absorption coefficients it would seem that these areas are not manganese non-metallic inclusions; since for the commoner manganese inclusions the contrast is greater with nickel and copper radiations than with cobalt radiation, appearing in the former cases darker and in the latter case lighter than the matrix. Although the contrast here is taken as the direct difference of the linear absorption coefficients, the sensitivity of the method cannot be readily assessed owing to the presence of the white radiation and to the unknown, and possibly variable, manganese content of these areas, affecting the absorption. Sharply defined segregates of this type have now been observed in a wide variety of steels.

Ball-Race Steels

The steel commonly used for ball bearings and races contains about 1% of chromium and 1% of carbon. Considerable differences in the running performances of steels which are nominally identical have been observed even when hardened to a similar degree, but the reason for such differences has not been established. A micro-radiographic examination of a number of these batches of steel has been made with the object of discovering any segregations which might help to explain these differences. Chromium is readily differentiated from a background of iron by the radiations of cobalt or iron, to which it is more absorptive, while with other radiations it would not be detected; such segregations can thus be differentiated from those of manganese by the fact that both are revealed by cobalt radiation, but only the former is revealed by iron radiation. Typical micro-radiographs obtained on these steels are shown in Figs. 4 to 8 and, while the work has not yet progressed to a point at which it is possible to correlate segregation with running life, it is clear that very marked differences in the character of the distribution of the alloying elements can occur. Figures 4 and 5 are identical areas of one sample of steel, and the disappearance of the sharply defined segregates with the change from cobalt to iron radiation proved them to be rich in manganese. The smaller segregates which are visible in both radiographs occur as tips or envelopes to the manganese segregates. These, therefore, contain a heavier element which, however, could not be identified with certainty, as they were found to be more absorptive than the iron with all radiations available. It seems probable that they are rich in tungsten. Figures 6 and 7 show similar micro-radiographs of a second batch of steel taken with cobalt and iron radiations and, whereas the manganese-rich segregates here are of a much finer and more elongated character than those shown in Fig. 4, marked segregation of chromium is also present as is revealed by the diffuse banding visible with both radiations. Such banding was not detected in the first batch of steel. Figure 8 is another example of a micro-radiograph of this class of steel taken with cobalt radiation and showing the clearly defined segregates of manganese.

Manganese Sulphide Inclusions

From the figures given in Table II it is apparent that most of the commoner inclusions in steel are less absorptive than the matrix with all radiations, and cannot be identified. Those containing manganese are, however, exceptions and, as an illustration, the appearance of manganese sulphide inclusions is given in Figs. 9, 10, and 11. Figure 9 shows the micrographic appearance of these inclusions, and Figs. 10 and 11 are micro-radiographs of the same area with cobalt and copper radiations respectively; the inclusions being more absorptive than iron to the former radiation and sufficiently less absorptive to be revealed by the latter.

The size of the inclusions appears larger in the micro-radiographs than in the photomicrograph, since in the former a projection of the whole inclusion through the thickness of the sample is recorded, while in the latter only the section in the surface is visible. This observation that manganese sulphide inclusions are visible as dark areas in radiographs taken with copper radiation is further proof, additional to the micrographic evidence, that the manganese-rich segregates previously described are of a different nature, for they were not detected with copper radiation. This sample also showed areas which were more highly absorptive to cobalt radiation than the sulphide inclusions and which did not show the absorption reversal with copper radiation characterizing the sulphide inclusions; these were evidently manganese-rich segregates similar to those previously described.

Miscellaneous Wrought Steels

A number of wrought steels, both alloyed and plain carbon, were examined in a similar manner, and the occurrence of the sharply defined segregates of manganese appeared to be quite normal. Some samples of steel, *e.g.*, the S82 used for the examination of overheating, had no such segregates, but in general they were present to a greater or less degree.

Cast Steels and Cast Iron

A few samples of cast materials were radiographed and, as would be expected, very beautiful structures were revealed when the steels were highly alloyed. Figures 12 and 13 show such a structure in a sample of cast austenitic heat-resisting steel to Air Ministry Specification D.T.D. 49B. The segregation of the alloying elements is clearly shown as the more absorptive areas in the neighbourhood of extensive interdendritic porosity. The micro-radiographs reproduced are of the same area taken with cobalt and chromium radiations respectively. With these highly alloyed steels the absorption coefficient of the base material must first be calculated for each wave-

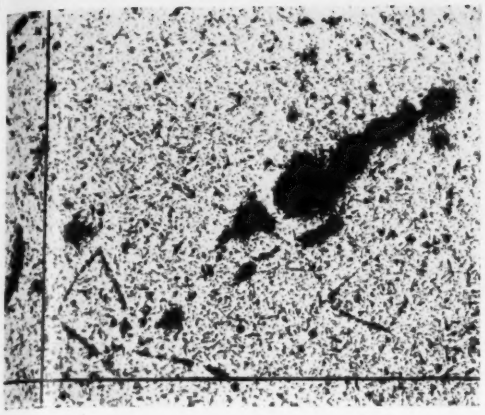

Fig. 2—Overheated S28, etched with nitro-sulphuric acid × 150

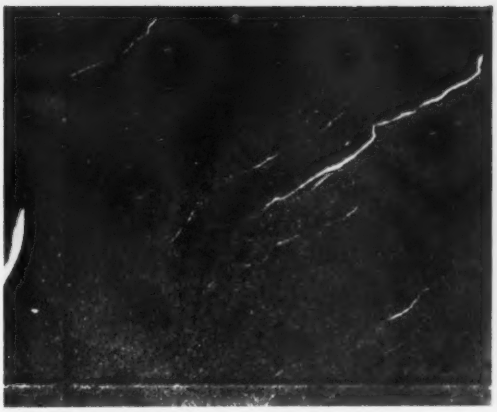

Fig. 3—Overheated S28, same area as in Fig. 2. Micro-radiograph with cobalt radiation × 150

Fig. 4—1% chromium–1% carbon ball-race steel, batch A. Micro-radiograph with cobalt radiation × 150

Fig. 5—1% chromium–1% carbon ball-race steel, same area as Fig. 4. Micro-radiograph with iron radiation × 150

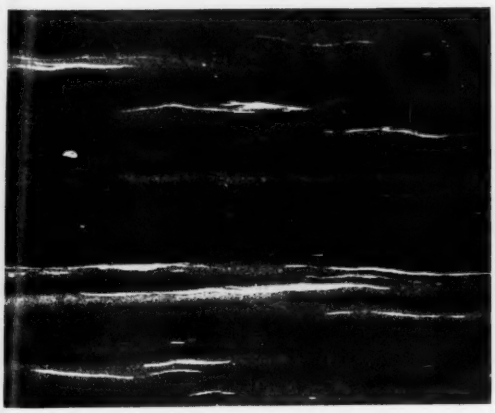

Fig. 6—1% chromium–1% carbon ball-race steel, batch B. Micro-radiograph with cobalt radiation × 150

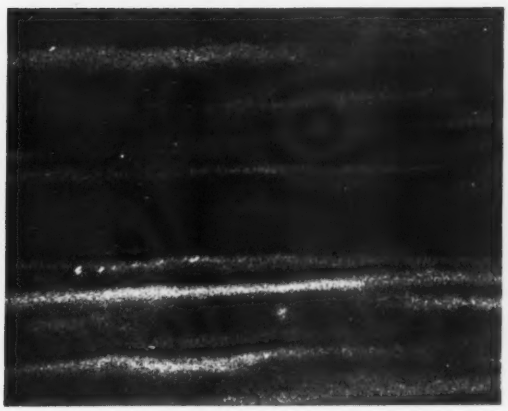

Fig. 7—1% chromium–1% carbon ball-race steel, same area as in Fig. 6. Micro-radiograph with iron radiation × 150

Fig. 8—1% chromium-1% carbon ball-race steel, batch C. Micro-radiograph with cobalt radiation × 100

Fig. 9—Manganese sulphide inclusions. Photomicrograph × 180

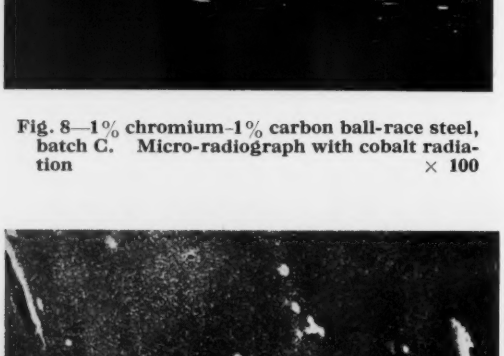

Fig. 10—Manganese sulphide inclusions, same area as in Fig. 9. Micro-radiograph with cobalt radiation × 180

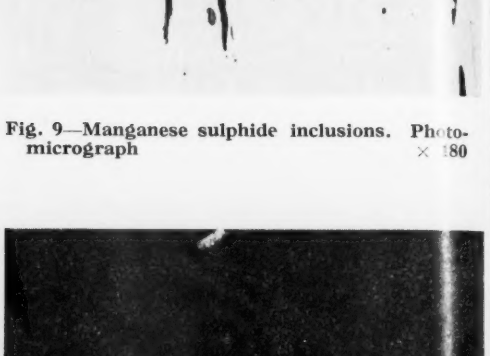

Fig. 11—Manganese sulphide inclusions, same area as in Fig. 9. Micro-radiograph with copper radiation × 180

Fig. 12—Cast D.T.D. 49B. Micro-radiograph with cobalt radiation × 150

Fig. 13—Cast D.T.D. 49B, same area as in Fig. 12. Micro-radiograph with chromium radiation × 150

Fig. 14—Cast iron. Micro-radiograph with cobalt radiation ×100

length, as it will differ appreciably from that of pure iron which was taken as the matrix of the low-alloyed steels previously considered; although, as the composition of the matrix will, in any case, differ from the mean composition of the steel, the coefficient cannot be determined with any great accuracy. Despite this uncertainty, it is apparent for this particular steel that chromium-rich segregations would be most clearly seen with cobalt and iron radiations, whilst tungsten-rich areas would be considerably more absorptive than the background to all radiations, but more especially to those from manganese and chromium targets. The interdendritic segregation shown in Fig. 12 is thus mainly chromium, whilst Fig. 13 shows the location of the discrete tungsten-rich areas within the chromium segregation and also adjacent to the porosity.

A sample of cast 10% manganese steel was examined and the excess manganese was found to occur as a continuous, rather diffuse segregation at the grain boundaries.

A recent paper by Salkovitz, Schaum, and Von Batchelder[12] deals with the appearance of graphite flakes in micro-radiographs of grey cast iron using white tungsten radiation. Figure 14 is the micro-radiograph of a grey cast iron, taken with characteristic cobalt radiation and, in addition to the graphite flakes, which are easily revealed by all radiations, the small white areas are indicative of manganese-rich areas since they were only visible with this radiation.

CONCLUSIONS

The examples described are sufficient to indicate the usefulness of micro-radiography in the examination of segregates and inclusions in steel. Most of the normal metallic alloying elements can be selectively revealed by a suitable choice of radiation; but non-metallic inclusions cannot, in general, be identified. Of particular interest is the apparent readiness of manganese to form into sharply defined segregates which are not easily diffused into uniform distribution, since they were detected even in an overheated steel. Although these areas are apparently quite distinct from manganese sulphide inclusions, the sharpness of their boundaries suggests that they may not be true segregates; being not merely regions of solid solution rich in manganese, but in fact actual separate phases which are not soluble in the matrix. It appears desirable that the nature and occurrence of these manganese-rich areas in relation to composition of the steel should be explored, and their influence on the mechanical properties determined, particularly in the case of high-tensile steels where small regions of a different composition, and thus different response to heat-treatment, are likely to have a strong effect especially on fatigue strength. Using the selective absorption method with cast materials, not only can segregates in highly alloyed steels be revealed, but also the actual distribution of the constituents within the segregates can be obtained.

Acknowledgments

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References

1. C. T. Heycock and F. H. Neville: *Transactions of the Chemical Society*, 1898, vol. 73, p. 714.
2. P. Goby: *Comptes Rendus*, 1913, vol. 156, p. 686.
3. M. F. Fournier: *Revue de Métallurgie*, 1939, vol. 35, p. 349.
4. J. J. Trillat: *Revue Scientifique*, 1940, vol. 78, p. 212.
5. G. L. Clark: *Photo Technique*, 1939, vol. 1, p. 19.
6. G. L. Clark and W. M. Shafer: *Transactions of the American Society for Metals*, 1941, vol. 29, p. 732.
7. G. L. Clark and S. T. Gross: *Industrial and Engineering Chemistry (Analytical Edition)*, 1942 vol. 14, p. 676.
8. S. E. Maddigan: *Journal of Applied Physics*, 1944, vol. 15, p. 43.
9. S. E. Maddigan and B. R. Zimmerman: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1944, vol. 156, p. 33.
10. A. Preece and others: *Journal of The Iron and Steel Institute*, 1946, No. 1, p. 273P.
11. G. W. Austin: *The Iron and Steel Institute*, 1936, *Special Report No.* 14, p. 189.
12. E. I. Salkovitz and others: 51st Convention of the American Foundrymen's Association, 1947, April.

Margam Cold-Reduction Plant

The new three-stand cold-reduction mill to be installed at the Abbey Works of the Steel Company of Wales, Ltd., will be housed in an additional building to be erected on the east side of the hot-mill finishing departments. Twin cooling conveyors 1000 ft. in length will bring the hot-reduced coils to this building, which will consist of five bays: The coil-storage and pickling bay (105 × 1400 ft.); the annealing bay (125 × 1000 ft.); the mill bay (105 × 1000 ft.); the processing bay (105 × 840 ft.); and the shipping bay (125 × 840 ft.).

The plant will consist of an 80-in. continuous pickle line with four 80-ft. acid tanks and an acid-recovery plant, and an 80-in. three-stand cold-reduction mill, each stand being driven by a 4000-h.p. motor. Coils weighing up to 30,000 lb. will be rolled up to 72 in. wide and down to 0·026 in. thick. Annealing will be carried out in coke-oven-gas fired portable-cover type furnaces, partly in coil form and partly in sheet form.

Three four-high single-stand skin-pass mills will be installed; one will skin-pass in coil form only, one in either coil or piece, and one in piece form only. The coils will be sheared into sheets by three coil cut-up lines, and, in addition, shears, oilers, levellers, circling machines, and other small plant will be included.

A personnel of 700 will be required, and the initial output will be 5000 tons per week, increasing to 7000 tons or more by the addition of further annealing plant. It is believed that the mill will have the highest finishing speed and horse-power of any three-stand 80-in. mill in the world.

A Magnetic Study of Phase-Change Processes in Iron–Silicon Alloys

By K. M. Guggenheimer, Ph.D., H. Heitler, Ph.D., and K. Hoselitz, Ph.D., F.Inst.P.

SYNOPSIS

The magnetic method of measuring the variation of magnetic saturation intensity, σ, with temperature, was used to investigate alloys of iron and silicon. Three magnetic phases, α, α'', and η, exist in this system, and σ–T curves of the three pure phases have been determined.

Methods to locate phase boundaries have been developed, and results have been obtained for various regions of the equilibrium diagram.

A quantitative method of magnetic analysis is described. This was used to investigate various phase-change processes and their dependence on time and temperature.

Introduction

MEASUREMENTS of the variation with temperature of the magnetic intensities of ferromagnetic alloys can be used to investigate equilibrium conditions and phase-change processes in the solid state. The method has been previously applied to the study of iron–nickel alloys (Pickles and Sucksmith,[1] and Hoselitz and Sucksmith[2]). These authors found that room-temperature magnetic intensities and the Curie temperature are characteristic for the composition of systems with two magnetic phases.

In the present investigation the method has been applied to the iron-rich iron–silicon alloys. In the temperature range 500–1150° C. the presence and the simultaneous transformation of three different magnetic phases can be determined, and it has been found possible to give a complete quantitative analysis of some reactions which occur in these alloys.

Previous X-ray investigations of this system, particularly the position of the phase boundaries, have been carried out by Haughton and Becker,[3] Stoughton and Greiner,[4] Osawa and Murata,[5] and Lipson and Weill.[6] The phase diagram arrived at by Stoughton and Greiner is shown in Fig. 1. From 0 to 15% of silicon only one phase, α, described as a solid solution of silicon in iron, is present. In alloys with from 15 to 33% of silicon, and at temperatures up to about 800° C., this saturated α phase is in equilibrium with the non-magnetic ε phase, with 33·4% of silicon, which corresponds to the composition FeSi. Between 800° and 1050° C. another phase (η) is in equilibrium either with α or ε and is stated to contain 25% of silicon (Fe_3Si_2). Above 1050° C. the state is again given as an equilibrium between $\alpha + \varepsilon$, the α solid-solution boundary being, however, near 20% of silicon.

Osawa and Murata describe a new modification of the α phase, α'', in the high-temperature region of the α-phase field of Stoughton and Greiner. They consider this α'' as a superstructure of the α phase. The limit of solubility of silicon in α iron is given by them as 18·6% ($Fe_{11}Si_5$). Furthermore, they ascribe to the η phase a composition of 23% of silicon (Fe_5Si_3).

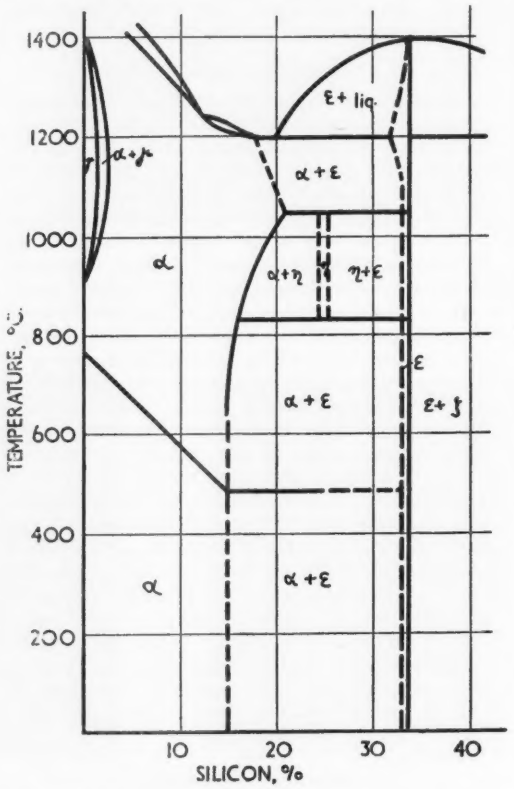

Fig. 1—Equilibrium diagram of the iron–silicon system (Stoughton and Greiner)

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Lipson and Weill confirmed the η phase as containing 23% of silicon, but found that the limit of the α solid solution below 750° C. is at 16% and moves at higher temperatures to about 19%. They studied a phase-change process in 25% silicon alloys at an annealing temperature of 720° C. They found that the amount of α phase was reduced to zero after 4 hr. and then increased to a maximum value. No distinction is made between α and α''.

In the present work, which was begun in 1942, an attempt has been made to clarify the divergent views, to locate by the magnetic method the phase boundary of the α solid solution and of the η phase, and to investigate the nature of the α'' phase, which is clearly distinguished by its magnetic properties from both α and η. The magnetic method proved to be particularly suitable for the study of the transformation of phases during annealing and the determination of the reactions which take place, their velocities, and the activation energies.

EXPERIMENTAL PROCEDURE

Iron–silicon alloys with silicon contents ranging from 3·9 to 30% by weight were obtained at first from Dr. H. Lipson, then of the Cavendish Laboratory, Cambridge, and later from Dr. Hoselitz, of the Permanent Magnet Association.

Specimens of between 10 and 50 mg. in weight were sealed in silica tubes and subjected to various heat-treatments. Measurements were then made in the magnetic balance (Sucksmith[7]). Some specimens were also heated up to 750° C. *in situ* in the balance, in order to study the velocities of the phase changes.

The experimental method consists of the measurement of the magnetic-saturation intensity per unit mass, σ, as a function of temperature, T, up to and above the Curie temperature, θ. The field of 16,000 oersted was sufficient to obtain saturation (Sucksmith[7]). For a single magnetic phase a smooth σ–T curve is obtained; σ decreases with rising temperature, slowly at first and then more steeply, and finally tails-off to disappear at temperatures considerably beyond θ. Owing to this tailing-off it is difficult to determine the exact value of the Curie temperature from the experimental curves. With the field employed it was found that for pure iron, used as a standard, the Curie point coincides with the point of steepest descent of the σ–T curve and consequently this criterion was applied in all curves for the determination of θ.

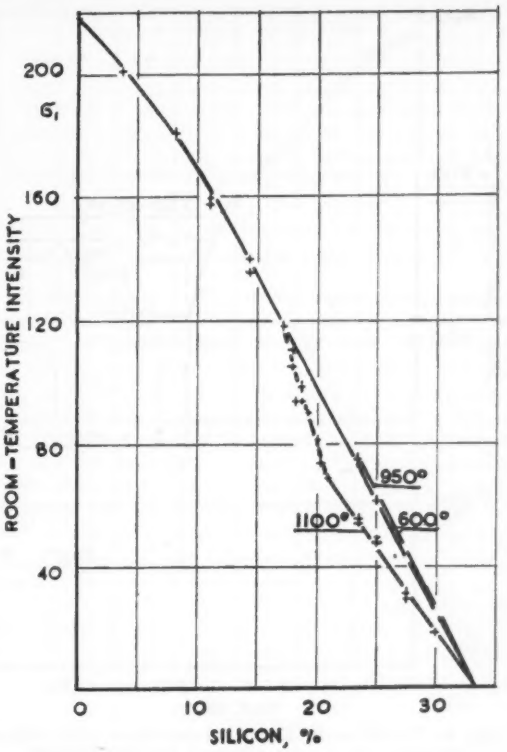

Fig. 3—Variation of magnetic room-temperature intensity, σ_1, with silicon content (wt.-%) for different heat-treatments

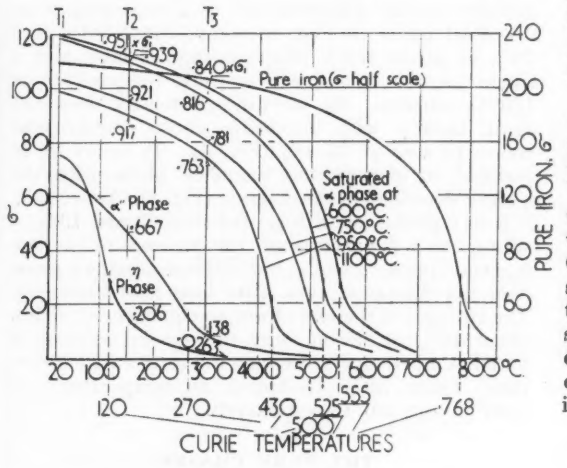

Fig. 2—Magnetic-intensity/temperature curves of the pure phases

Since the conclusions reached in this work do not depend on absolute, but only on relative, values of Curie temperature, a systematic error in the Curie-point determinations will not influence the results.

As a first step, the relationships in various temperature regions between magnetic intensity at room temperature, σ_1, and silicon content, and between Curie temperature and silicon content, have been systematically studied. It can be seen from Fig. 3 how the intensity at room temperature varies with the silicon content and with the heat-treatment. The dependence of the Curie temperature upon the silicon content and temperature of heat-treatment is shown in Fig. 4.

THE THREE TEMPERATURE REGIONS

There are three main temperature regions to be distinguished in the phase diagram (Fig. 1), namely:

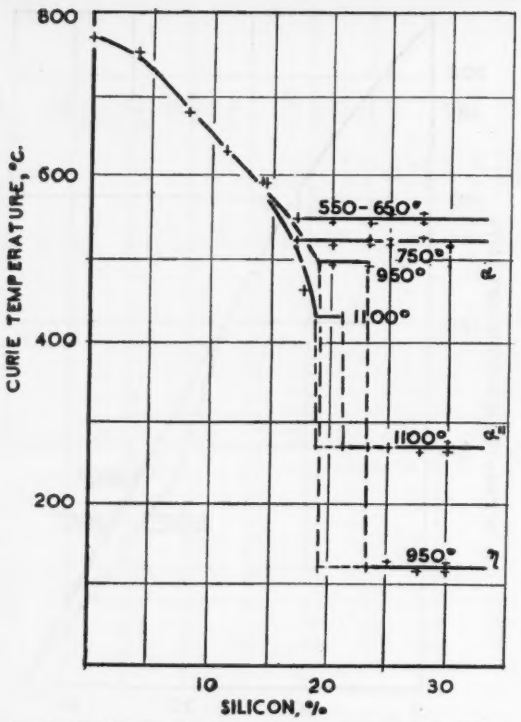

Fig. 4—Variation of Curie temperature with silicon content (wt.-%) for different heat-treatments

(*a*) T above 1030° C., (*b*) T below 830° C., and (*c*) T = 830–1030° C.

***(a)* Heat-Treatment at Temperatures above 1030° C.**

As a preliminary heat-treatment all specimens were heated to 1100° C. for 4 hr. and quenched in cold water. A prolongation of the heating to 24 hr. did not result in any change of the magnetic properties, and 4 hr. were therefore considered to be sufficient to produce a stable state. It was, however, found that the quenching had to be very rapid, and it was essential to have silica tubes with thin walls, and a small specimen with a high surface-to-volume ratio. A slightly retarded cooling resulted in transformation into other phases.

For specimens containing more than about 21% of silicon, the σ–T curves (*see* Fig. 2, α'' curve) show only one Curie temperature, at 270° C., independent of the composition (*see* Fig. 4). This Curie point is characteristic of the α'' phase. The room-temperature intensity decreases linearly with increasing silicon content and vanishes at 33·4% (*see* Fig. 3), which composition corresponds to the ε phase, FeSi. This is evidence for the fact that α'' and ε are present in these alloys.

With less than 19% of silicon also a single magnetic phase is obtained (Fig. 2, α phase at 1100° C.). However, the shape of the σ–T curve is completely different from that of alloys with more than 21% of silicon. The intensities are much higher and the Curie temperature is not independent of composition but increases steadily with decreasing silicon content (Fig. 4). This is a magnetic characteristic of a solid solution, and is attributed to the α phase.

The region between 19 and 21% shows the presence of two magnetic phases (α and α'') and will be dealt with later, together with the determination of the phase boundaries.

***(b)* Heat-Treatment at Temperatures below 830° C.**

When the specimens are treated at temperatures between 550° and 750° C. after the initial heat-treatment at 1100° C. the α'' phase disappears completely within a comparatively short time, *e.g.*, in a few hours at 550° C. Alloys with silicon contents below 17% show again a single magnetic phase with a σ–T curve shape similar to that of alloys quenched from 1100° C. (Fig. 2, α phase 750° and 600° C.). The room-temperature intensities and the Curie temperature are, however, higher than those of corresponding specimens treated at 1100° C., but the difference becomes less the lower the silicon content (Figs. 3 and 4).

For compositions of more than 17% of silicon, two magnetic phases are obtained, one having a Curie point at about 120° C. and the other at about 540° C. After very long treatment the phase with the low Curie temperature disappears and the other phase remains the only stable magnetic phase. The shape of σ–T curves of such alloys is typical for the α-phase (Fig. 2). The room-temperature intensity decreases linearly with increasing silicon content and comes to zero at 33·4% of silicon (Fig. 3), this being again the composition of the non-magnetic ε phase which is in equilibrium with the α phase. The Curie temperature, however, remains constant for alloys with between 17 and 33·4% of silicon. Below 17% of silicon it increases steadily with decreasing silicon content in a way similar to that described for the 1100° C. region (Fig. 4).

***(c)* Heat-Treatment at Temperatures of 830–1030° C.**

Heat-treatment in this temperature region results initially in the formation of the same phases as described under (*b*), but in compositions with over 23% of silicon the α phase disappears later and a single magnetic phase with a Curie temperature of 120° C. remains. Its saturation intensity decreases again linearly with increasing silicon content and comes to zero at 33·4% (Fig. 3). It seems to be justified to identify this magnetic phase with the η phase described in the diagram (Fig. 1). Above 23% it is in equilibrium with ε. Between 23 and 19% of silicon the σ–T curves show the presence of the two magnetic phases α and η, but in this region the α phase does not disappear even after long heat-treatment. The two phases therefore form an equilibrium. Below about 19% of silicon, only the α solid solution is found. Curie temperatures and intensities are between those found after treatment at temperatures of 1100° C. and 750° C. respectively.

THE PURE PHASES

In order to follow in greater detail the phase changes and to analyse and to interpret the experimental

curves with two and three magnetic phases, it is essential to know the exact chemical composition and the magnetic properties of the pure phases.

Three different magnetic phases have been found, the α, α'', and η phases, which are stable in the temperature regions previously described. As already mentioned, any of these phases can occur together with non-magnetic ε if the silicon content of the specimens is higher than the limit of the α solid solution. In such mixtures the room-temperature intensity, σ_1, decreases therefore linearly with increasing silicon content, while the Curie temperature remains constant, as has been described. The composition of the pure phase without ε is thus determined as that of the specimen with the highest intensity σ_1 of a range of alloys having a single magnetic-phase curve with a constant Curie temperature. The accuracy of this method of determination of the phase composition depends on the range of specimens available and on the knowledge of the chemical composition of the alloys. With the specimens available in the present work the following upper limits of composition for α, α'', and η at the temperatures given below were found:

Phase	Silicon, %	Temp., °C.
α	17·2	<750
α''	20·8	1100
η	23·0	950

There are, however, other ways of determining the composition of pure phases corroborating these results.

α SOLID SOLUTION

The Curie temperature of the solid solution decreases with increasing silicon content until saturation is reached, and then remains constant with further additions of silicon. The discontinuity in the curve of composition plotted against θ determines the limit of solubility of silicon in iron (*see* Fig. 4). The curve of composition against σ_1 also shows a change of direction at this silicon content, but this change is not so pronounced, as can be seen by inspection of Fig. 3.

In Figs. 5 and 6 the Curie temperature is plotted against intensity, σ_1. Figure 5 contains the measurements for alloys treated at 600° and 750° C., and Fig. 6 for 950° and 1100° C. The point where the θ–σ_1 line suddenly changes direction determines again the specific intensity $\sigma_\alpha°$ of the pure saturated α phase. For the construction of these curves it is not necessary to know the chemical composition of all the specimens.

The composition of the saturated α phase in equilibrium at the four respective temperatures can be read off Fig. 3 as that corresponding to the specific intensities $\sigma_\alpha°$ of the knee points of curves of Figs. 5 and 6.

It is found that above 700° C. the solubility of silicon in iron increases and $\sigma_\alpha°$ decreases. The values of limiting solubility obtained in this way for various temperatures are as follows:

Values of Limiting Solubility

Heat-Treatment Temp., °C.	θ	$\sigma_\alpha°$	Silicon, %
550–650	555	119	17·2
750	525	118	17·2
950	500	103	19·3
1100	430	98	19·0

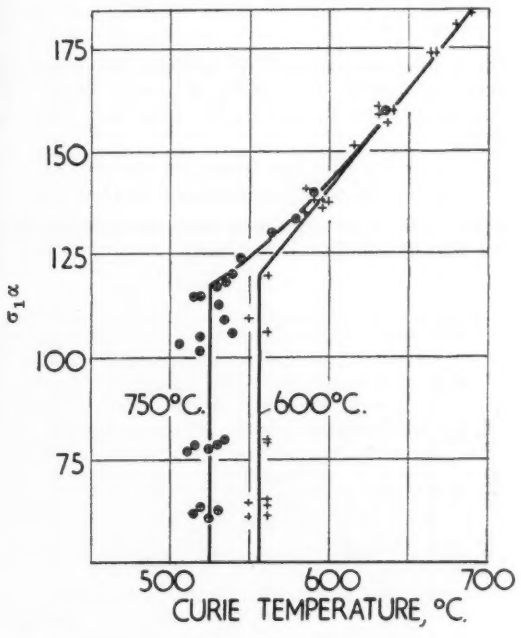

Fig. 5—Relation between Curie temperature and room-temperature intensity, $\sigma_1\alpha$, for alloys annealed at 600° and 750° C.

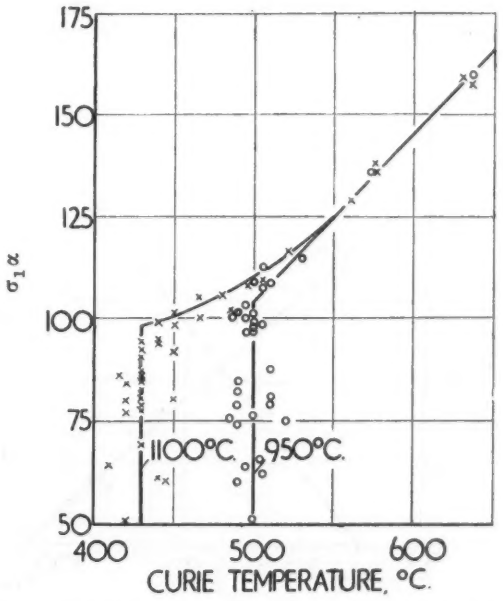

Fig. 6—Relation between Curie temperature and room-temperature intensity, $\sigma_1\alpha$, for alloys annealed at 950° and 1100° C.

It can be seen that the values for 550–650° C. are in agreement with the more approximate method mentioned earlier.

The procedure described above is, however, applicable only to solid solutions with variable θ and not therefore to the α'' and η phase with defined chemical composition.

In alloys with silicon of 14–17%, which are in the single-phase state of the α solid solution, an increase in Curie temperature was observed after annealing at temperatures below 750° C. (*see* Fig. 4). A superstructure has been found to exist in iron–silicon alloys round the composition Fe_3Si (14·5% of silicon) (Farquhar, Lipson, and Weill[9]). Sucksmith[8] and Thompson[10] found that in iron–nickel–aluminium and nickel–manganese alloys the Curie temperature of the ordered structure is higher than that of the corresponding disordered one. It is, therefore, not unreasonable to suggest that the increase of θ found in the present work for decreasing temperatures of heat-treatment, is due to an ordering phenomenon.

TWO-PHASE REGIONS

In the $\alpha + \alpha''$ and $\alpha + \eta$ regions of the equilibrium diagram, both components are magnetic. The σ–T curves of alloys in these phase fields show a superposition of the curves of the two phases. The two Curie temperatures in each σ–T curve are clearly distinguishable. It is obvious that, *e.g.*, in the $\alpha + \eta$ region, the amount of α varies linearly from 100% to zero as the silicon content increases from pure-α to pure-η composition. The intensities at room temperatemperature (T_1) of the α and η phase contribution, *i.e.*, $\sigma_{1\alpha}$ and $\sigma_{1\eta}$, respectively, vary accordingly from $\sigma_{1\alpha}{}^{\circ}$ (intensity of pure α) to 0 and from 0 to $\sigma_{1\eta}{}^{\circ}$.

To determine $\sigma_{1\alpha}$ and $\sigma_{1\eta}$, a knowledge of the shape of the single-phase curves and their relative intensities at various temperatures is sufficient. The σ–T curves of specimens with a single magnetic phase with some ε can serve to determine the ratios of σ_2 and σ_3—the intensities at $T_2 = 150°$ C. and $T_3 = 300°$ C. respectively—to σ_1, the intensity at room temperature. It has been found that these ratios are constants, independent of the amount of ε phase in the mixture, and they are denoted by the symbols:

$$a_2 = \frac{\sigma_{2\alpha}}{\sigma_{1\alpha}}; \quad \eta_2 = \frac{\sigma_{2\eta}}{\sigma_{1\eta}}.$$

In the two-phase curves, which are similar in character to three-phase curves, such as is shown in Fig. 9, we have:

$$\sigma_1 = \sigma_{1\alpha} + \sigma_{1\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1a)$$
$$\sigma_2 = \sigma_{2\alpha} + \sigma_{2\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1b)$$

From these equations $\sigma_{1\alpha}$ and $\sigma_{1\eta}$ can be evaluated from the measured intensities σ_1 and σ_2 at T_1 and T_2 respectively, as follows:

$$\sigma_{1\alpha} = \frac{\sigma_2 - \eta_2\sigma_1}{a_2 - \eta_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2a)$$

$$\sigma_{1\eta} = \frac{\sigma_2 - a_2\sigma_1}{\eta_2 - a_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2b)$$

If, now, various σ–T curves are analysed in this way, and the values of $\sigma_{1\alpha}$ and $\sigma_{1\eta}$ are found, they can be plotted against σ_1 (Fig. 7). Two straight lines are obtained which intersect the axis at certain values of σ_1. These values of σ_1 correspond to $\sigma_{1\alpha}{}^{\circ}$ and $\sigma_{1\eta}{}^{\circ}$ and have been evaluated as follows:

$\sigma_{1\alpha}^{\circ} = 103$, after heat-treatment at 950° C.
$\sigma_{1\eta}^{\circ} = 75$

This is in agreement with the previous determination from Fig. 3 (σ–Si, %) and Fig. 6 (θ–σ_1). The $\alpha + \alpha''$ region has been treated in the same way (Fig. 8), giving:

$\sigma_{1\alpha}^{\circ} = 98$, after heat-treatment at 1100° C.
$\sigma_{1\alpha''}^{\circ} = 68$, after heat-treatment at 1100° C.

which again is in agreement with the determination (*see* Fig. 3) mentioned previously.

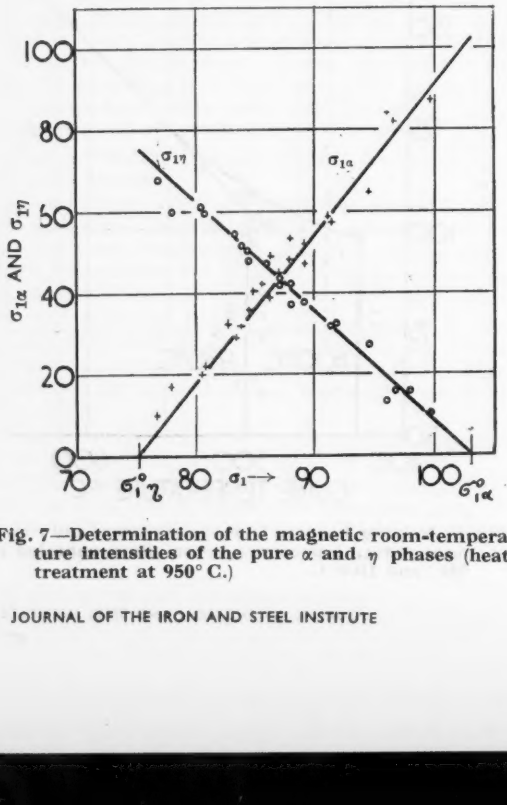

Fig. 7—Determination of the magnetic room-temperature intensities of the pure α and η phases (heat-treatment at 950° C.)

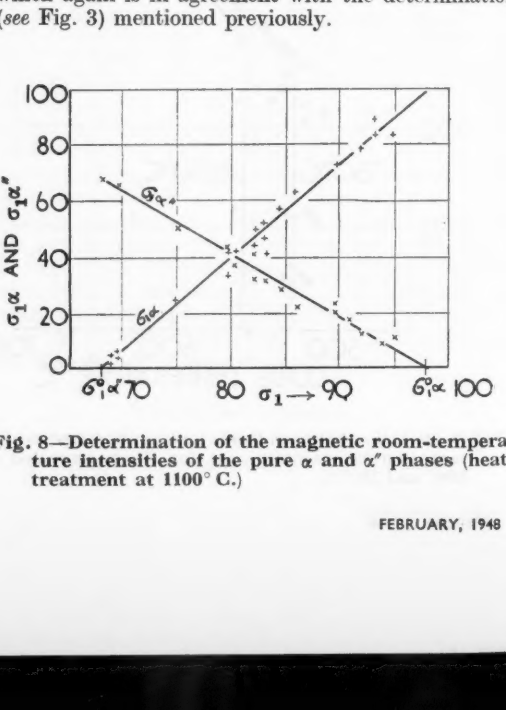

Fig. 8—Determination of the magnetic room-temperature intensities of the pure α and α'' phases (heat-treatment at 1100° C.)

Table I

VARIOUS VALUES FOR THE THREE MAGNETIC PHASES

Phase	Heat-Treatment Temp., ° C.	Curie Temp., ° C.	σ_1°	σ_2° $T_2 = 150°$ C.	σ_3° $T_3 = 300°$ C.	$\sigma_2^\circ/\sigma_1^\circ$	$\sigma_3^\circ/\sigma_1^\circ$	Si, %
α	550–650	555	119	113	100	0·951	0·840	17·2
α	750	525	118	106	96	0·939	0·816	17·2
α	950	500	103	95	80·5	0·921	0·781	19·3
α	1100	430	98	90	75	0·917	0·763	19·0
η	950	120	75	15·4	2·0	0·206	0·0263	23·2
α''	1100	270	68	45·3	9·4	0·667	0·138	20·8

The full graphs relating to Table I are shown in Fig. 2

The silicon contents of the pure phases can now be read off from Fig. 3. They are :

Phase	Silicon, %	Temp., ° C.
α	19·3	950
η	23·2	950
α	19·0	1100
α''	20·8	1100

The ratio $\sigma_{1\alpha}/\sigma^\circ_{1\alpha} = \omega_\alpha$, that is, the intensity due to the amount of the α phase present divided by the intensity of the pure phase alone, represents the relative weight of α phase contained in the specimen. Similarly $\omega\alpha''$ and $\omega\eta$, the relative amounts of α'' and η phase, respectively, are obtained.

If two magnetic phases are in equilibrium the sum of the relative amounts of the phases in the alloy must be equal to 1, *i.e.* :

$$\omega_\alpha + \omega_\eta = 1 \quad \text{or} \quad \omega_\alpha + \omega_{\alpha''} = 1 \quad \text{.....(3)}$$

If these ω values are multiplied with the silicon content of the pure phases the contributions of each phase to the total silicon content of the alloy are obtained. Their sum should agree with the total silicon content of the specimen. This relation can serve as a check of the results of the magnetic analysis.

If one of the magnetic phases, say, α, is in equilibrium with ε, the amount of ε, ω_ϵ, is obtained by the difference $1 - \omega\alpha$ and the silicon content can be calculated in the same way and should agree with the silicon content determined by chemical analysis. Table I gives some characteristic values for the three magnetic phases ; the full graphs are shown in Fig. 2.

THREE-PHASE SYSTEMS

In the process of transition from the equilibrium state at 1100° C. ($\alpha'' + \varepsilon$) to the equilibrium at 750° C. or lower, it has been shown that an intermediate state with three magnetic phases occurs, one of which is the η phase, unstable in the low-temperature region. The three phases are clearly distinguished by the inflections in the σ–T curves, indicating the three Curie temperatures. Furthermore, it must also be expected that the non-magnetic ε phase is present in amounts varying according to the total silicon content of the specimen.

In Fig. 9 an example is given of a three-phase σ–T curve for an alloy with 21% of silicon after quenching at 1100° C. and annealing at 550° C.

In an analogous way to that used for alloys in the two-phase region, systems with three magnetic phases can be analysed as follows :

$$\sigma_1 = \sigma_{1\alpha} + \sigma_{1\eta} + \sigma_{1\alpha''} \quad \text{.....(4)}$$

with similar equations for 150° C. and 300° C. from which $\sigma_{1\alpha}$, $\sigma_{1\eta}$, and $\sigma_{1\alpha''}$ can be evaluated.

The weight proportions of the phases present must obey the equation :

$$\omega_\alpha + \omega_\eta + \omega_{\alpha''} + \omega_\epsilon = 1 \quad \text{.....(5)}$$

The total silicon content of the alloy, as found by chemical analysis, must be equal to the sum of the silicon contributions due to the four phases respectively, *i.e.* :

$$\omega_\alpha p_\alpha + \omega_\eta p_\eta + \omega_{\alpha''} p_{\alpha''} + \omega_\epsilon p_\epsilon = p_{Si} \quad \text{.....(6)}$$

where, *e.g.*, p_α = Si, wt.-%, of the pure phase, and p_{Si} = Si,%, of the specimen.

All three-phase σ–T curves have been analysed in this way. Table II gives examples with values of ω's and total silicon content by magnetic analysis compared with the chemical composition. The constitution of one and the same alloy varies with the heat-treatment and agreement with the chemical composition is independent of the variation of the phase composition.

X-RAY PHOTOGRAPHS AND PHOTOMETRY

Since the magnetic method of establishing the presence of various phases and of determining the boundaries in the phase diagram is comparatively

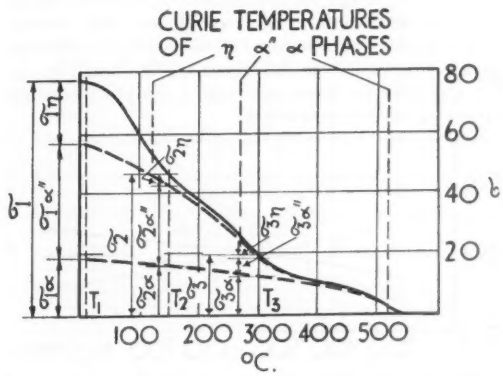

Fig. 9—A three-phase σ-T curve and its components of the three magnetic phases α, α'', and η

Table II

RESULTS OF QUANTITATIVE MAGNETIC ANALYSIS OF SOME THREE-PHASE σ–T CURVES, AND COMPARISON WITH TOTAL SILICON CONTENT

ω_α	$\omega_{\alpha''}$	ω_η	ω_ϵ	Contribution to Total Si Content by Each Phase, wt-%				Si, %
				α	α''	η	ϵ	
Nominal Composition: 23% of Silicon (by weight)								
0·000	0·822	0·000	0·178	0·0	17·1	0·0	6·0	23·1
0·062	0·706	0·071	0·161	1·2	14·7	1·6	5·4	22·9
0·283	0·000	0·556	0·161	4·8	...	12·9	5·4	23·1
0·363	...	0·430	0·207	6·2	...	10·0	6·9	23·1
0·422	...	0·348	0·230	7·2	...	8·0	7·7	22·9
0·470	...	0·294	0·236	8·1	...	6·8	7·9	22·8
0·057	...	0·903	0·040	1·1	...	20·9	1·3	23·3
Nominal Composition: 25% of Silicon (by weight)								
0·016	0·551	0·113	0·320	0·3	11·5	2·6	10·7	25·1
0·072	0·433	0·151	0·344	1·2	9·0	3·5	11·5	25·2
0·141	0·285	0·250	0·324	2·4	5·9	5·8	10·9	25·2
0·224	0·026	0·410	0·340	3·8	0·5	9·5	11·4	25·2
0·109	...	0·669	0·222	1·9	...	15·5	7·4	24·8
Nominal Composition: 27·5% of Silicon (by weight)								
0·015	0·412	0·044	0·529	0·3	8·6	1·0	17·7	27·6
0·126	0·171	0·200	0·503	2·2	3·6	4·6	16·9	27·3
0·196	...	0·259	0·545	3·4	...	6·0	18·3	27·7
0·036	...	0·550	0·414	0·7	...	12·7	13·9	27·3
Nominal Composition: 30% of Silicon (by weight)								
0·009	0·247	0·013	0·731	0·2	5·1	0·3	24·4	30·0
0·050	0·135	0·080	0·735	0·9	2·8	1·9	24·6	30·2
0·100	0·015	0·158	0·727	1·8	0·3	3·7	24·3	30·1
0·102	0·006	0·161	0·731	1·7	0·1	3·7	24·4	29·9
0·044	...	0·302	0·654	0·9	...	7·0	21·9	29·8
HoE*								
0·090	...	0·870	0·040	1·7	...	20·2	1·3	23·2
0·007	0·748	0·059	0·189	0·1	15·6	1·4	6·3	23·4

* Specimen of originally unknown chemical composition, analysed magnetically only.

new, it was felt desirable to confirm the magnetic results by X-ray data. In particular, powder photographs of specimens which had been magnetically determined to be pure single-phased, were examined. Here it was found that in such specimens only the lines of the one phase appear, and there was no trace of even the strongest lines of any of the other phases, thus confirming the results of magnetic measurements.

The small difference in lattice spacing between the α and α'' phase, found by other workers, was confirmed. It is worth mentioning that two phases with closely similar crystal parameters show widely different magnetic properties, as described earlier (*see* Fig. 2).

For quantitative measurements a simple recording photometer was constructed.

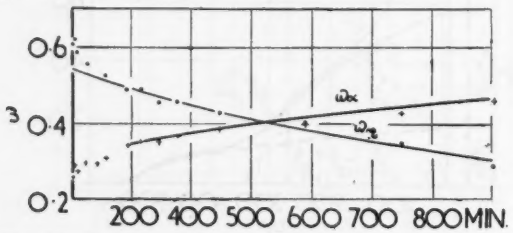

Fig. 10—Change of the relative weight amounts, ω, of the α and η phases with time of anneal at 735° C. in a specimen with 23% of silicon

A well-defined light beam passing through the X-ray film falls on a selenium photocell which is directly connected to a sensitive galvanometer. The deflection, together with the zero position, is recorded on bromide paper which is moved together with the film, thus reproducing the distance and intensities of the lines. Series of records show clearly the systematic change of the intensity of phase lines with composition, and fully confirm the results of the magnetic measurements.

There is also evidence that the lattice spacing of the α phase varies slightly with the temperature of heat-treatment. An effect of this kind is to be expected, as a result of the order–disorder transformation of Fe_3Si, which is naturally not restricted to exactly this composition. The ordering phenomenon is generally accompanied by a diminution in lattice parameter (*see, e.g.*, Bradley and Taylor,[11] and Nix and Shockley[12]). A change in Curie point which is probably connected with the ordering process has been mentioned earlier.

PHASE TRANSFORMATIONS

It has been shown that there are three temperature regions, above 1030, 1030–830°, and below 830° C., in which the equilibrium conditions are quite different. Thus, if specimens which have reached equilibrium at 1100° C. are then treated at lower temperatures,

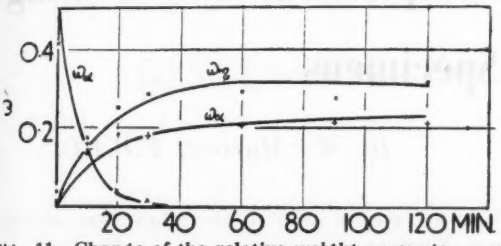

Fig. 11—Change of the relative weight amounts, ω, of the α, α'', and η phases with time of anneal at 650° C. in a specimen with 27·5% of silicon

phase reactions proceed with velocities dependent on the temperature chosen. The general qualitative character of these transformations, as observed by changes in σ–T curves, has been described already. With the aid of the quantitative analysis, both for the two- and three-phase states, it is now possible to gain quantitative information about their dependence upon time at chosen annealing temperatures. In Figs. 10 to 13 the amounts of phases as determined by the method described are plotted as a function of time of annealing for different heat-treatments.

Figure 10 shows results for a 23% silicon specimen annealed at 735° C. The α'' phase disappears too quickly at this temperature to be measured. Within less than 10 min. there is no trace of α'', and α and η are already fully formed. With continuing heat-treatment the amount of η phase clearly diminishes steadily. Since originally no η was present, it must have gone through a maximum value also within the first few minutes. The α phase increases steadily, and so does the amount of ε, which can be calculated according to $\omega_\varepsilon = 1 - \omega_\alpha - \omega_\eta$. In this experiment, for which the heat-treatment was applied *in situ*, the annealing time was not sufficient to reach equilibrium, but specimens annealed for 7 days and for 21 days showed very small amounts of the η phase present. After 9 weeks at 700° C., η had practically vanished.

Figure 11, in which these conditions are plotted for an annealing treatment at 650° C. of a specimen with 27·5% of silicon, shows the initial processes a little more clearly since at the lower temperature they are somewhat slower. The decrease of α'' and the initial increase of α and η become measurable.

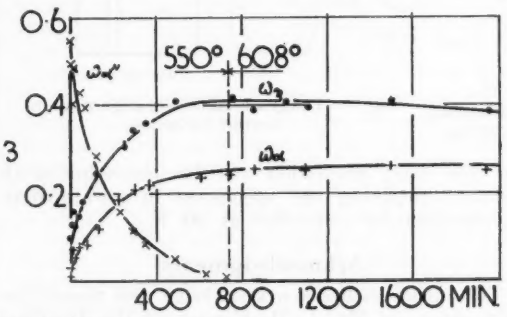

Fig. 12—Change of the relative weight amounts, ω, of the α, α'', and η phases with time of anneal at 550° C. for 740 min. and 608° C. thereafter in a specimen with 25% of silicon

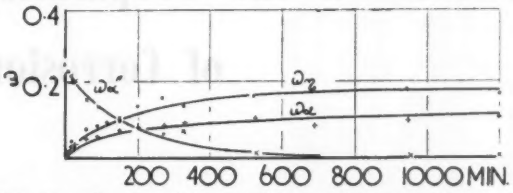

Fig. 13—Change of the relative weight amounts, ω, of the α, α'', and η phases with time of anneal at 550° C. in a specimen with 30% of silicon

In Figs. 12 and 13, representing the results of heat-treating *in situ* at 550° C. specimens with 25% and 30% of silicon, respectively, the initial reactions have become very clear, and it can be seen that the speeds of the initial reactions, that is, the decrease of α'' and the increase of both α and η, are of the same order of magnitude. In the former case the temperature was raised after 740 min. by 58° C. in order to increase the speed of the phase changes after the initial period and to get some indication of the velocity of the final reaction. The decay of the η phase is so slow at that temperature that the reaction approaches completion only after several months.

This investigation shows that the magnetic analysis is useful to determine the various reactions occurring in ferromagnetic alloys during transition from one equilibrium region to another. Even several simultaneous processes can be separated and measured quantitatively. Results of this study as well as of the chemical interpretation of the phase-change processes and the kinetics of the reactions will be discussed in another paper.[13]

Acknowledgments

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References

1. Pickles and Sucksmith: *Proceedings of the Royal Society*, 1940, series A, vol. 175, p. 331.
2. Hoselitz and Sucksmith, *Proceedings of the Royal Society*, 1943, series A, vol. 181, p. 303.
3. Haughton and Becker: *Journal of The Iron and Steel Institute*, 1930, No. I, p. 315.
4. Stoughton and Greiner: "Metals Handbook," p. 396. Cleveland, Ohio: American Society for Metals.
5. Osawa and Murata: *Nippon Kinzoku Gakkai-Si*, 1940, vol. 4, p. 228.
6. Lipson and Weill: *Transactions of the Faraday Society*, 1943, vol. 39, p. 13.
7. Sucksmith: *Proceedings of the Royal Society*, 1939, series A, vol. 170, p. 551.
8. Sucksmith: *Proceedings of the Royal Society*, 1939, series A, vol. 171, p. 525.
9. Farquhar, Lipson, and Weill: *Journal of The Iron and Steel Institute*, 1945, No. II, p. 457P.
10. Thompson: *Proceedings of the Physical Society*, 1940, vol. 52, p. 217.
11. Bradley and Taylor: *Proceedings of the Royal Society*, 1937, series A, vol. 159, p. 56.
12. Nix and Shockley: *Reviews of Modern Physics* 1939, vol. 10, p. 1.
13. Guggenheimer and Heitler: In the press.

A Note on the Preparation, Suspension, and Testing of Corrosion Specimens

By W. Murray, F.R.I.C.

In the course of experiments on the inhibition of corrosion of metals completely immersed in water the duplication of results was found to be impossible. Modification in the method of preparation and suspension of specimens overcame the difficulty and it is felt that they are worthy of recording.

Single-Metal Specimens

It seemed clear to the author that the suspension medium should be of the same character as the specimen under test and that so far as possible the medium should be cut from the original bar in such a way that there was no marked change in the cross-section of the hook from that of the specimen. These objects are achieved by the method shown diagrammatically in Fig. 1. Figure 1 (*a*) represents a 1-in. square mild-steel bar, from which specimens may be cut approximately ¼ in. thick and then strips taken from the same bar (and in the same plane) as shown at "*a*" in the bar. Figure 1 (*b*) shows a hook prepared from a metal strip in position in the specimen, and Fig. 1 (*c*) the arrangement of the specimen in the test-bottle.

Local stresses set up by work done on the specimen and the hook, *e.g.*, by tapping and screwing, are not considered to be any real detriment as this is inseparable from normal plant practice.

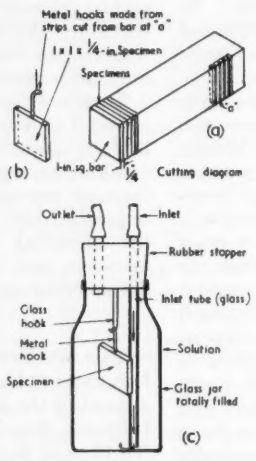


Fig. 1—New method of suspension of metal specimens

Bimetallic Specimens

With bimetallic specimens, in addition to the question of suspension, there is also that of ensuring good contact between the two metals—brass and steel in the author's experiments. The brass specimen and hook were turned complete from the bar, *i.e.*, there was no screwed joint (*see* Fig. 2). As will be seen from Fig. 2 the brass and steel were coupled by internal tapping and screwing.

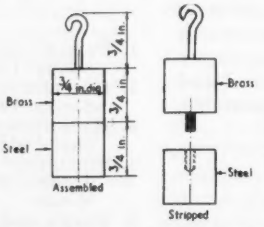


Fig. 2—Method of obtaining good bi-metallic contact

Layout

The layout for one circuit consisted of a cold-water circulating system open to the atmosphere at one point (Fig 3).

A ten-feed oil-lubrication pump, suitably modified, provided the circulation. Aeration of the circulated water was aided by glass wool in the funnels.

Testing at 90° F.

Tests at 90° F. were carried out to furnish information of the conditions in condenser cooling circuits (again open to the atmosphere at one point). The only modification necessary to the technique used for cold-water circulation was the immersion of all bottles containing the specimens in a water-bath thermostatically controlled at 90° F.

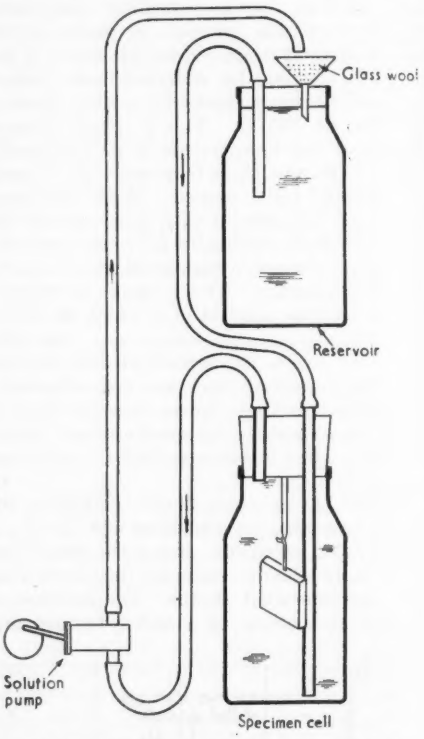


Fig. 3—Diagrammatic arrangement of layout for tests

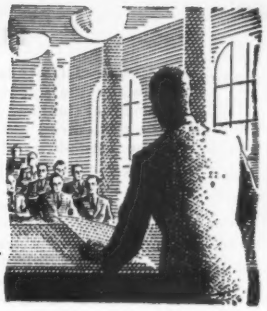
Acknowledgments

The author wishes to acknowledge with thanks the help given by Mr. J. MacGregor, of the Distillers Co., Ltd., in preparing the specimens, and by Feedwater Specialists Company, Maxwell House, Liverpool, for providing laboratory facilities.

Mr. Murray is Water-Treatment Consultant with the Feedwater Specialists Section of Liverpool Borax Co., Ltd.

Manuscript received 16th September, 1947.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

DISCUSSION AT

A Joint Meeting on Desulphurization and Dephosphorization of Cupola Iron and Pig Iron

A Joint Meeting of the Institute of British Foundrymen and The Iron and Steel Institute, in which the British Iron and Steel Research Association was invited to participate, was held at the Offices of The Iron and Steel Institute on Wednesday, 19th March, 1947. Mr. D. HOWARD WOOD, President of the Institute of British Foundrymen, was in the Chair; Dr. C. H. DESCH, F.R.S., President of The Iron and Steel Institute, was absent in America, but Sir CHARLES GOODEVE, F.R.S., Director of the British Iron and Steel Research Association, was present, and conveyed a message of regret from him to the meeting.

At the MORNING SESSION, starting at 10.30 A.M., the First and Second Reports of the Basic Cupola Sub-Committee (T.S.10) of the Technical Council of the Institute of British Foundrymen was presented by Mr. L. W. BOLTON, Chairman of the Sub-Committee. Following a Buffet Luncheon, the AFTERNOON SESSION commenced at 2.15 P.M. and Mr. BOLTON presented a Report on the Desulphurization and Dephosphorization of Cupola Iron and Pig Iron in Basic Lined Ladles, also prepared by the Basic Cupola Sub-Committee.

Summaries of the three Reports and of the discussion are printed below; the Reports in full and a report of the Meeting will also be found in *Foundry Trade Journal* and in the *Proceedings of the Institute of British Foundrymen.*

SUMMARY OF THE PROCEEDINGS AT THE MORNING SESSION

The **Chairman**, opening the Meeting, said that the work referred to in the Reports began under war-time conditions, and it was made clear that the full-scale production technique for reducing the sulphur and phosphorus contents in cupola-melted irons described would not be economically possible in normal circumstances. He believed, however, that in the not too distant future the iron and steel industry in Great Britain would have to depend more on materials with sulphur and phosphorus contents of the order of those used during the recent war, and he was glad to announce that the British Iron and Steel Research Association had made arrangements for this research to continue; representatives of the Sub-Committee of the Institute of British Foundrymen would be invited to collaborate.

Sir **Charles Goodeve,** F.R.S., said that the success of the further work under the ægis of the British Iron and Steel Research Association depended on the continued support of the Institute of British Foundrymen and the British Cast Iron Research Association.

Mr. **L. W. Bolton** then presented the First* and Second† Reports of the Basic Cupola Sub-Committee of the Institute of British Foundrymen. He said that the conclusions to be drawn from the Sub-Committee's work were that (*a*) basic refractories which would give good service in the cupola were available, but there was still room for improvement in their properties, so that further research was required; (*b*) with suitable conditions a high degree of desulphurization in the basic cupola was possible, and with carefully controlled conditions cupola dephosphorization was practicable, but further work on the latter was required before any theory of the reactions involved could be put forward.

* For full Report see *Proceedings of the Institute of British Foundrymen*, 1943/44, vol. 37, pp. A133–A146.

† *Proceedings of the Institute of British Foundrymen*, 1945/46, vol. 39, pp. A195–A198.

FIRST REPORT ON THE BASIC CUPOLA

In cupolas with acid, *i.e.*, firebrick and ganister linings, it is not possible to produce the basic slag necessary to reduce the sulphur and phosphorus contents of the metal during melting. In certain applications, for example in the melting of ferromanganese, excessive wear is experienced on acid linings. Improvements in basic refractories and the development of a stabilized dolomite patching cement have caused renewed interest in the possibilities of lining cupolas with basic material.

A monolithic lining of stabilized dolomite was installed in a small cupola melting ferromanganese used in the production of manganese steel. The lining withstood the melting conditions better than a firebrick lining and erosion was reduced.

A lining of stabilized dolomite when used in a cupola of 36-in. bore enabled metal to be produced with a sulphur content less than 50% of that normally expected when melting similar mixtures with an acid lining.

The possibilities offered by the basic cupola of obtaining dephosphorization during melting were examined. In preliminary melts using charges of low silicon (0·77% of silicon) pig iron containing 0·74% of phosphorus, iron ore was added with the charges to assist in creating an oxidizing slag. Phosphorus removal varied from 5 to 50% and was almost dependent on silicon removal. Samples which showed the maximum silicon loss also showed maximum dephosphorization. When the charged metal contained 0·05% of silicon and 0·6% of phosphorus, the phosphorus content was reduced by 80% without the addition of an oxidant. The inclusion of ferrosilicon in the charge reduced the dephosphorization to about 40%, but the reduction was not in proportion to the amount of ferrosilicon added. Oxidizing conditions favourable to dephosphorization were found to restrict desulphurization.

SECOND REPORT ON THE BASIC CUPOLA

A cupola of 90-in. bore was provided with a monolithic lining of stabilized dolomite. Charges of 100% of steel scrap were used for steelmaking by the converter process. Silicon additions to the charges were kept to a minimum and the possibility of obtaining dephosphorization of already low phosphorus metal during melting was studied.

The average run of steel scrap used in the experiments contained 0·065 to 0·085% of phosphorus. Some measure of dephosphorization and desulphurization was obtained on all the trial melts. For a period during one melt, highly oxidizing conditions were produced in the cupola and over 50% of the phosphorus in the metal was removed. The metal produced under these conditions was, however, unsuitable for further processing. When conditions were not unduly oxidizing, phosphorus removal did not take place to any marked degree. The cupola slags were found to contain P_2O_5 in amounts sufficient to account for the whole of the phosphorus removed from the metal.

The experiments confirm that the stabilized dolomite material is satisfactory as a lining for a cupola and that stabilized dolomite cement is a satisfactory patching material. With carefully controlled conditions of operation, dephosphorization of low phosphorus metal during cupola melting is shown to be possible. The Sub-Committee is of the opinion that further experimental work might result in the development of a commercial process and, in view of the importance of this matter to the industry, hope that arrangements for further work may be made.

Dr. **W. C. Newell** (British Iron and Steel Research Association) thought that insufficient consideration had been given to the effect of temperature. Much information on desulphurization and dephosphorization reactions at steelmaking temperatures was available, but for iron melting the temperature was some 200° C. lower, and that made a big difference. The few temperature readings were taken by optical pyrometer; the immersion pyrometer would have been more suitable. A comparison of the temperatures in basic- and acid-lined cupolas would have been interesting. He then discussed the chemical reactions involved in dephosphorization and desulphurization and the influence of temperature on the equilibria, to show that dephosphorization was aided by basic, oxidizing conditions, and low temperature, whereas desulphurization was promoted by basic, reducing conditions, high temperature helping when manganese was the principal desulphurizing agent and low temperature being required with soda.

In one case the Sub-Committee obtained, at Stanton, a higher carbon content in a basic than in an acid lining, in conformity with an earlier conclusion of Heiken, but Dr. Newell thought that this was due to the high lime charge and to a possibly lower temperature and was not to be ascribed to the lining material.

Concerning the type of lining, he thought that the case for bricks was not proved, and asked why a monolithic lining should not be used. When a high ferromanganese charge was melted in a basic lining the dephosphorization was not appreciable but there was less wear on the refractory. This increased lining life was interesting but was a separate issue and should be kept apart from the present tests.

In a further reference to dephosphorization he pointed out that in the first set of experiments the phosphorus removed from the metal could not be accounted for in the slag, and asked for an explanation. Finally, he referred to Heuer's suggestion that when desulphurizing with a highly basic slag the conditions should be made more reducing by depressing the CO pressure by bubbling nitrogen through the melt.

It seemed that dephosphorization and desulphurization could be effected in the cupola, but required antagonistic conditions; he thought that one process should be carried out in the cupola and the other in the ladle.

Mr. **L. W. Bolton** agreed with Dr. Newell about temperature determinations, but the work had been carried out under commercial works conditions, and in any case an exploration of the temperatures at which reactions took place inside the cupola would be very difficult. General experience was that the higher the temperature in a cupola the higher was the carbon pick-up; hence it would appear, contrary to Dr. Newell's suggestion, that the temperatures at Stanton were higher than those in other experiments. The experiment with the melting of ferromanganese was the only one where the main interest lay in a longer lining life; the slag produced was highly basic,

and eroded an acid lining very badly. As to simultaneous removal of sulphur and phosphorus, it seemed that this should be possible, because oxidizing and reducing conditions could exist simultaneously in different zones in the cupola.

Mr. **P. Murray** (British Iron and Steel Research Association), also replying to Dr. Newell, stated that basic monolithic linings failed mainly by flaking of the working face; acid monolithic linings usually failed from slag attack. The First Report gave a wrong impression of the relative merits of brick and monolithic linings. In the earlier work bricks appeared to have no important advantages over monolithic linings, but later, circle bricks gave so much better service that their use had become standard practice at the works in question. The cost of basic refractories was about six times that of acid materials normally used in cupola linings. Referring to the chemistry of the reactions discussed by Dr. Newell, heats of reaction could not give quantitative relationships when several reactions were proceeding simultaneously; it then became necessary to use free-energy equations, and these applied only to equilibrium conditions. The reactions in cupolas were much more complex than those in batch furnaces. Analyses of slag samples taken from the tuyere level and at the tapping spout had shown that the equilibrium responsible for the removal of phosphorus was easily displaced, and reversion might occur in the well. To study the process, therefore, thermodynamic considerations could not be applied and reaction kinetics must be studied.

Mr. **F. L. Robertson** (John Summers and Sons, Ltd.) said that the Sub-Committee considered the Heuer process to be represented thus:

$$C + FeS + CaO \rightleftharpoons CaS + Fe + CO$$

The partial pressure of the CO was very small, and blowing nitrogen through the slag removed it. Ordinary blast-furnace slag with a little lime was used, and in a 30-ton ladle, ratios of sulphur in the slag to that in the metal as high as 8000 : 1 were claimed.

Mr. **S. Spray** (Stanton Ironworks Co., Ltd.) commented that oxidizing conditions in cupola practice might affect the subsequent iron castings and they could also result in poor blowing in the converter. Subsequent deoxidation before blowing or other use might be the answer. Concerning phosphorus elimination he thought much of it occurred during the following desulphurization. Most of the temperatures recorded were measured by optical pyrometer; when immersion-pyrometer readings were also obtained the optical pyrometer was always found to be about 100° C. low. Mr. Spray agreed with Dr. Newell that the temperatures in the earlier Stanton tests had been lower than normal, owing to a scaffold in the cupola, which had set up oxidizing conditions leading to very high dephosphorization.

Mr. **E. J. Brown** (Hadfields, Ltd.) said that for 30 years his firm had melted ferromanganese in cupolas lined with Austrian magnesite, suitably bonded. When this material ceased to be available in 1939, stabilized dolomite was successfully bonded and used in cupolas and ladle linings; for lining cupolas, however, it was very wasteful, and the cupola was discarded in favour of the reverberatory furnace for melting ferromanganese. Concerning chemical bonds and the ramming properties of stabilized dolomite, there had been two early difficulties: The rapid dehydration, which made the ramming time too short, and the causticity, which attacked the workmen's hands. This was overcome by the addition of ½% of a vegetable oil. He did not agree with Mr. Bolton's view that the increased carbon pick-up could be ascribed to intermittent tapping; he thought it more likely to be due to some mechanical cause—molten drops were enveloped in a protective slag in the acid process, but not in the basic process.

Mr. **L. W. Bolton** wished to correct any impression that he attributed the increased carbon pick-up to intermittent tapping. In experiments described in the First Report there was no increase in carbon over that normally obtained in an acid lining; the metal was tapped continuously over a front tapping spout. At Stanton the metal was stored in the well, and, being held in contact with the coke for a longer time, the carbon content ran much higher than those previously recorded with a normal acid lining and intermittent tapping. He thought the higher carbon pick-up in the basic than in the acid cupola was due to the difference in the type of slag.

Mr. **P. Murray** (British Iron and Steel Research Association) said that, basic materials being non-plastic, plasticizers were added, and these caused the attack on the workmen's hands; leather gloves should be worn. There was no need to add oil to the ramming material. The use of liquid sodium silicate to increase medium-temperature strength was only partly successful, because it migrated to the surface during drying, producing a hard skin and softer interior; chemical bonds should not be water-soluble. Magnesite was not used in these experiments; there was little doubt that it resisted erosion by ferrous oxide slags better than other basic refractories, yet even so, magnesite-brick linings would have to be patched. It had been suggested that a magnesite lining should be used without patching until worn out, but he thought that the rate of erosion would be so high as to make this scheme unworkable, though water-cooling might help.

Dr. **T. P. Colclough** (Iron and Steel Control) suggested that the difference in the carbon contents of cupola metal melted in a basic and a ganister lining could be explained by the fact that the absorption of carbon by melted scrap in the presence of excess carbon was a function of time and temperature. In the First Report tests, the syphon spout removed the metal as fast as it was melted, so that there was no carbon pick-up. At Stanton, the well stored 3 tons of metal which was in contact with the coke for at least 10 min.; the carbon absorption was usually between 2·8 and 3·2%. With basic practice the temperature was normally higher, and at Stanton it was very high (1450–1480° C.), approaching blast-furnace conditions.

Dr. Colclough thought that the three questions, (*a*) the use of basic linings in the cupola, (*b*) desulphurization, and (*c*) dephosphorization, should be

examined separately. The basic lining was a problem in itself. Desulphurization required, besides a basic lining a basic slag, reducing conditions, and a higher temperature, and that meant higher coke consumption; he claimed that it was more economic to desulphurize outside the cupola. Dephosphorization demanded oxidizing conditions, which were antipathetic to the conditions for desulphurizing; he thought that Dr. Newell had omitted the most important reaction in this respect, namely, that between carbon and P_2O_5.

Mr. **L. W. Bolton** felt that the question of carbon pick-up had not yet been solved. In the automobile industry cupolas produced metal as hot as, if not hotter than, that at Stanton, and the charge composition with respect to carbon (2·5% of carbon; using steel scrap, cast iron scrap, and pig iron) was higher than at Stanton. Carbon figures of 3·85% were never met with. He did not expect the difference between the silicon contents of the two types of metal to account for the large difference in the carbon pick-up. He had seen wells as deep, in proportion to the melting rate, as that at Stanton. Whether desulphurization should be done inside or outside the cupola depended, he thought, on circumstances.

Mr. **H. Morrogh** (British Cast Iron Research Association) said that the mechanical and founding properties of cast iron were affected considerably by high phosphorus contents, so that, as there was a shortage of native low phosphorus raw materials the basic cupola was of considerable interest to the iron-founder; the sulphur content, provided that it was adequately balanced by the manganese, was of relatively small consequence in the foundry. The Reports dealt with the removal of relatively low ranges of phosphorus contents, whereas the foundryman was concerned with higher ranges; dephosphorization from say, 1·5% down to 0·8% would be a great step forward. The silicon content of the charge metal seemed to be the limiting factor; for appreciable dephosphorization a low silicon content must be tolerated. He wondered whether it would be economical to dephosphorize low silicon material and then restore the silicon content by adding ferrosilicon. Mr. Morrogh asked about the founding qualities—fluidity, shrinkage, freedom from blow-holes, etc.—of grey iron made in the basic cupola; did melting in the basic cupola affect the graphite structure? For future work he suggested an investigation to show whether sulphur and phosphorus were removed in the shaft or in the well, or both—that dephosphorization proceeded further when silicon was added separately suggested that the reaction took place appreciably in the shaft—and the repetition, with a basic cupola, of an earlier experiment in which the entire cupola stack was water-cooled, in order to throw light on carbon pick-up as well as the zones where sulphur and phosphorus were removed. He added that Dr. Newell had omitted reference to a very important desulphurizing reaction in cupola melting, namely, the straightforward reaction between sulphide or sulphur in the coke and manganese in the metal, producing desulphurization by the segregation of manganese sulphide—a reaction that was less efficacious at higher temperatures.

Mr. **L. W. Bolton** replied that grey iron melted in a basic cupola appeared to have properties very similar to those of acid-melted material, though the silicon loss was a little higher.

Mr. **J. L. Harrison** (Catton and Co., Ltd.) said he had tried using a cupola lined with stabilized dolomite bricks to melt metal for blowing in a side-blown converter, with interesting but not very promising results. Limestone and fluorspar were used to achieve dephosphorization, and figures of 0·01–0·02% of phosphorus with a very low silicon value were obtained. The temperature was about 1285–1380° C. The carbon increased by 0·3–0·5%, owing to pick-up in the well. The rate of melting was very low, and no reason could be suggested. The process was expensive. One reason for the success of the basic process was that the metal flowed through a thick blanket of slag. Tapping must be continuous, and if sulphur and/or phosphorus were removed in the cupola an intermediate stage for reheating and resiliconizing the metal must be considered.

Mr. **L. W. Bolton** observed that Mr. Harrison's temperatures were rather lower than the Sub-Committee's, and his phosphorus figures were very low; more attention must be paid to temperature in the future. He also had experienced a low melting rate in his first trials with a basic cupola; when the flux charge was adjusted to produce a fluid slag the melting rate became normal. The cost of the basic process at present was high, and it could be economic only if it conferred benefits not obtainable in any other way; improvements in basic refractories should, however, lead to more economical operation. He was interested in Mr. Harrison's statement that very low silicon metal must be reheated before it could be blown to steel; whilst superheating was practised at Stanton, he would have thought it possible to produce low silicon iron at a temperature high enough to allow an addition of cold or preheated ferrosilicon and subsequent conversion to steel.

Mr. **J. L. Francis** (Foundry Services, Ltd.) remarked that at Stanton, despite the increased blast, applied in an attempt to increase the oxidizing condition, they were still under-blowing, as shown by the unusually high coke ratio of 1 : 6·3; that might have some bearing on the carbon pick-up. When adding iron oxide to get oxidizing conditions, did it matter, he asked, whether Fe_2O_3 or Fe_3O_4 were used?

Mr. **L. W. Bolton**, referring to carbon pick-up, stressed the point that, with 100% steel charges, the carbon contents obtained were nearly 1% higher in the basic than in the acid cupola. Charges of 100% steel scrap, melted at high temperatures with a plentiful coke supply and stored in the well for long periods, were not uncommon in acid practice, but it was only with basic cupolas that carbon figures of 4% had been produced; so far, no explanation for this was known. He agreed with Mr. Francis that when the attempt was made to increase the oxidizing conditions by increasing the blast the cupola was still under-blown, but pointed out that this applied equally to the acid cupola quoted for comparison.

Mr. **H. Parnham** (General Refractories, Ltd.) said that both stabilized dolomite linings and firebricks

needed to be patched. Besides mechanical abrasion, even with hard-fired vitrified stabilized dolomite bricks there was a certain amount of chemical erosion to be made good daily; most of the wear in rammed linings, however, was due to mechanical abrasion. Chemical bonds made the mass stronger; hence, vitrification during operation went deeper, which might cause deeper flaking and so put up the costs. What was wanted was a very abrasion-resisting non-spalling brick, preferably of the magnesite type, which was volume stable. The hot zone should be designed for the use of a 4½-in. brick, and this, he suggested, should be 'run to death' without any patching; then the cupola should be relined, for it was nearly as expensive to patch as to reline it.

Mr. **L. W. Bolton** said that patching needed supervision if it was to be done correctly. This difficulty had been overcome by water-cooling the melting and superheating zones of the cupola. A refractory wash could then be put over the steel plates, and patching became a thing of the past. This was successful with pig-iron and cast-iron scrap charges, but not with 100% steel charges, because molten mild steel was deposited on the plates and built up in time (the steel did not pick up carbon till fairly low in the cupola). He had seen Mr. Parnham's suggested method of running the brick lining to death in operation at a foundry far removed from supplies of refractories, where the metal was melted at very high temperatures for 8 hr. continuously; it was considered most economical to replace the whole of the 4½-in. silica-brick lining in the hottest zone after each melt. It was interesting that a thin lining would stand up for a considerable time owing to the greater heat losses.

Mr. **W. W. Harrison** (Bagshawe and Co., Ltd.) said that the basic lining should become of great benefit to producers of whiteheart malleable cast iron. The cupola metal had to be very hot to run the castings, so that desulphurization outside the cupola was not practicable, yet the sulphur in the charge was high owing to the use of return scrap from runners and feeders.

The meeting then adjourned until the afternoon

SUMMARY OF THE PROCEEDINGS AT THE AFTERNOON SESSION

Mr. **L. W. Bolton** presented the Sub-Committee's "Report on Desulphurization and Dephosphorization of Cupola Iron and Pig Iron in Basic Lined Ladles" * (the third report for discussion).

REPORT ON DESULPHURIZATION AND DEPHOSPHORIZATION OF CUPOLA IRON AND PIG IRON IN BASIC LINED LADLES

Using basic-lined ladles and the newly developed technique of double pouring, it is possible to reduce an initial sulphur content of 0·20% down to 0·045%. A sulphur reduction of 75–80% can be obtained consistently. These results have been obtained with metal handled in batches of 5 tons. The Sub-Committee believes that there need be no limit to the size of batches of metal so treated.

In investigating the desulphurization of low silicon cast iron of the type produced from a cupola when melting 100% of steel scrap, it was found that treatment with soda ash removed an appreciable amount of phosphorus. Attempts have been made to increase the efficiency of phosphorus removal by the use of an oxidizing agent with the sodium carbonate. In a full-scale commercial trial, a low silicon cupola-melted metal had its phosphorus content reduced from 0·045%down to 0·036%, a reduction of 20%. The temperature loss in carrying out this treatment is not appreciably greater than in normal desulphurization and the metal can afterwards be used successfully for steelmaking by the converter process.

Mr. **F. L. Robertson** (John Summers and Sons, Ltd.) stressed the need, mentioned in the last paragraph of the Conclusions of the Report, for the continuation of research on the removal of phosphorus and silicon at low temperatures—1300–1400° C.—a matter of great importance to ingot makers for the production of low phosphorus and particularly low sulphur steel at a cheap price. (Desulphurization was not referred to, as it was assumed that ironmasters were using the soda-ash treatment as precisely as steel foundrymen, who reduced the sulphur to 0·02% with ease and regularity.) The chemistry of dephosphorization was known well enough to enable us to state the P_2O_5 content of the slag at which it was safe to tap any grade of carbon steel under any particular slag. The chemistry of desulphurization was not so clear; by reference to two diagrams, Mr. Robertson discussed the influence of low contents of sulphur, phosphorus, and silicon in the charge in reducing the amount of slag required, and remarked that the growing demand for low sulphur steels was being met abroad by the use of materials low in the elements named so that the slag weight was only 8–12% of the steel weight, as compared with 20–30% in Great Britain, where there was a shortage of suitable raw materials.

Mr. **D. Joyce** (Consett Iron Co., Ltd.), who was mainly concerned with desulphurization of pig iron, said that, whereas the sulphur could be easily reduced from 0·09% to 0·03%, it was much more difficult to get an initial figure of 0·03% down to 0·02%. This might be due in part to silica pick-up from the sand, but there seemed to be something in the soda-ash process over which there was no control. The speed at which the iron ran into the ladle affected the reaction, increased agitation increasing its efficiency. His best effort had been to reduce the sulphur from 0·023% to 0·009% with soda ash amounting to 20% of the weight of the metal.

* *Proceedings of the Institute of British Foundrymen*, 1946/47, vol. 40, pp. B15–B40.

Mr. **L. W. Bolton** suggested that Mr. Joyce would have got better results by the double-pouring method than by using such a high proportion of soda ash.

Mr. **N. L. Evans** (Imperial Chemical Industries, Ltd., Alkali Division) said that the principal variables in the desulphurization of iron by means of sodium carbonate were the composition and temperature of the metal and of the desulphurizing slag, the ratio of metal weight to slag weight, and the degree of contact between the slag and the metal. Some of these could be better controlled than others. The most serious contaminator of soda slag was silica, which was derived from furnace slag allowed to enter the ladle, from silicon extracted from the metal (a matter of chemical equilibrium under conditions of time, temperature, and composition), or from the ladle lining. Most ladle linings were siliceous; they were attacked by alkaline slags, the more so when new, and less when they became impregnated with alkaline slag and glazed. Rammed linings were more attacked than fired bricks. Broadly speaking, with present siliceous ladle linings and using 1% of sodium carbonate, 50% of the sulphur originally in the iron could be removed. Basic lining materials now available had vastly increased the efficiency of sodium carbonate treatment by minimizing the adulteration of the soda slag by silica. Rammed linings of tarred calcined dolomite gave very good results (up to 70% reduction of sulphur content), but they hydrated in the atmosphere, and the only real cure was to keep them hot some protection was also afforded by a surface oating of soda slag); if this condition could not be fulfilled, fired stabilized dolomite bricks should be used, though their small silica content would have a slight adverse effect. It had been observed in practice that soda-ash treatment could cause some slight dephosphorization; laboratory experiments, in which the two essential conditions, alkalinity and oxidation, were provided by having the molten iron in a basic-lined vessel and treating it with a slag made of sodium carbonate and mill scale, showed that with low silicon (0·12%) iron the phosphorus could be reduced from 0·47% to 0·15% (the P_2O_5 in the slag amounting to 28%), but with high silicon (1·35%) iron the decrease was only from 0·94% to 0·88%. In both cases the carbon and silicon contents dropped markedly. These results were confirmed in full-scale foundry tests.

Dr. **T. P. Colclough** said that desulphurization on a large scale was first practised about twelve years ago in the Saar. The iron to be treated was too cold for a solid reagent to be added for fear of skulling, so molten soda ash was trickled into the iron stream as it ran from the end of the runner into the ladle. Contact between the slag and metal (a most important point) was small, however, and the efficiency of the process low, so the so-called ' teapot ' ladle (the origin of the double pouring method) was devised. The metal, in 60-ton ladles, was poured into this mixer, which already contained some metal with old slag on it, and the slag was brought into intimate contact with the metal; the metal and slag was run out into a second ladle, in which the slag rose to the surface and ran away. About a 70% removal of the sulphur was achieved. The efficiency of desulphurization should be judged by the amount of sulphur removed by the quantity of soda ash actually used in comparison with what ought to have been sufficient. At present the efficiency was variable but always much too low. The reason was that sodium carbonate decomposed into sodium oxide and CO_2, and the oxide would combine to form either sodium sulphide or sodium silicate; to prevent the latter reaction (and this explained why silica must be kept out of the soda ash) limestone, which reacted with sodium oxide as quickly as did sand, was added—equal parts of soda ash and limestone was the ideal mixture, to which some fluorspar was added to keep the melting point low. The CO_2 liberated when the limestone was heated stirred up the mixture, making the slag–metal contact more intimate, and a very high desulphurizing efficiency (due in part to the interaction of CaO) could be attained. A stirrer consisting of two stopper rods attached to a horizontal arm and rotated in the slag–metal mixture in the ladle helped to bring about thorough mixing. The use of basic ladle linings for soda-ash treatment was wasteful; certain works were regularly reducing a sulphur content in the pig iron of about 0·3% to about 0·035% in the finished steel, and their ladles were lined with firebrick.

Mr. **E. T. Gill** (Edgar Allen and Co., Ltd.) thought that dephosphorization would have little application at the present stage in the making of side-blown converter steel; the material had to be almost free from silicon, yet that element was essential in the subsequent blowing process.

Mr. **L. W. Bolton** agreed that resiliconization was necessary; the metal should, however, be hot enough to take the required addition of silicon and still give a good blow.

Mr. **N. L. Evans** referred to the high melting point of the slag produced when limestone and soda ash were used as the desulphurizing agent; it could, of course, be reduced by adding fluorspar, but this material had a severe action on the ladle lining. Further, the method was not so successful with small as with large batches, when the stirring effect of the heavier stream of metal entering the ladle was greater; also, lids fitted to the ladle could maintain the high temperature. The teapot-spout ladle did not originate in Germany; it had been in use more than twelve years ago in Britain.

Mr. **R. D. Dick** (Pease and Partners, Ltd.) confirmed Mr. Evans' remarks on the use of soda-ash plus lime for desulphurizing. Pig iron in quantities of up to 4–5 tons when poured on to this mixture was pitted with gas holes and was only fit for scrap, and the desulphurization was low. Better efficiency was achieved with a receiver 15 ft. high by 2½ ft. in diameter than with an ordinary 5-ton foundry ladle. When desulphurizing hematite the double-pouring method seemed necessary, as the large amount of kish formed wasted the soda ash.

Mr. **J. L. Harrison** (Catton and Co., Ltd.) said that experiments to replace soda ash by a mixture of

common salt and calcium carbonate alone had not been successful, but better results have been obtained with this mixture in conjunction with soda ash. He had used Dephos (an American synthetic slab mixture containing about 64% of calcium ferrite, some sodium nitrate (to help melt the calcium ferrite, about 1% of charcoal and 12% of 50% ferrosilicon) as a dephosphorizer for converter-blown heats; used on the lines of the Yocum process it worked well, giving phosphorus figures of 0·012%, but the resulting steel was not suitable for making castings. Next, two heats of 0·5%-silicon metal (which would not raise the temperature too much) were partly blown till free from silicon and manganese; the metal then contained about 2½% of carbon, the conditions were highly oxidizing, and the temperature was about 1450° C. After removing the slag the metal was poured into a ladle of Dephos; the dephosphorizing slag was then removed and the metal returned to the converter, ferrosilicon added, and the blow completed. In one trial, using a firebrick-lined ladle, the phosphorus was reduced from 0·031% to 0·023%, whilst in the other the figure sank from 0·023% to 0·021%. Using Dephos in conjunction with soda ash (about 30 lb. of each per ton of metal), the sulphur in an ordinary cupola-melted metal (carbon, 3·0–3·3%; silicon, 1%) was reduced by 32% and the phosphorus by 27%.

Mr. **E. J. Brown** (Hadfields, Ltd.) believed that the first suggestion of the use of caustic materials to remove sulphur had come from Germany, when caustic soda was proposed. In discussing the efficiency of the elimination of sulphur or phosphorus, besides the extent of the reduction an indication of the relative amount of reagent used should also be given. Agitation should be as great as possible, and a long drop in pouring helped in this respect.

Mr. **N. L. Evans** said caustic soda should not be used for four reasons: (i) Being hygroscopic, there was a danger of a steam explosion; (ii) it was very unpleasant to use; (iii) it gave off no CO_2, so that there was no gas agitation of the melt; and (iv) it cost three times as much as soda ash.

Mr. **J. E. Mercer** (Head Wrightson and Co., Ltd.) remarked that castings with too high a sulphur content failed to meet acceptance tests and were liable to hot tears. Dolocrete, as a rammed lining material for ladles had not been successful; many skulls had formed, probably owing to the low temperature of the metal. He had experienced trouble with a big receiver in front of the cupola; the 3-in. internal bore, 12-ft. long, firebrick-lined channel from the cupola to the receiver burnt out before the day was over, but on lining the channel with cores of steel-moulder's compo the life was increased threefold without much erosion. This siliceous material was next tried in the melting plant; about 2 in. were rammed on ladle bottoms, using a former and pneumatic peening hammer. Soda ash (28 lb. per ton of metal) was put in the first ladle into which the receiver metal was tapped; metal and slag were then poured into the second ladle, and limestone chippings (12 lb./ton) were stirred in vigorously; this facilitated slagging off and ensured clean ladle metal for transfer to the converter. The following were typical results:

Test No.	Sulphur Content of Metal, %		
	Receiver	1st Ladle	2nd Ladle
1	(*a*) 0·090	0·023	0·013
	(*b*) 0·093	0·026	0·012
2	(*a*) 0·101	0·041	0·020
	(*b*) 0·105	0·040	0·023
3	(*a*) 0·108	...	0·033
	(*b*) 0·110	...	

(*a*) Combustion method. (*b*) Gravimetric method.

Dr. **A. H. B. Cross** (Thos. Firth and John Brown, Ltd.) pointed out that in desulphurization by soda ash the sodium oxide did not remove the sulphur entirely as sulphide, but that sulphite and sulphate could also be found in certain desulphurizing slags after use. The dry slag sample must be kept in a dry neutral atmosphere before analysis in order to avoid complex chemical changes.

Dr. **F. D. Richardson** (British Iron and Steel Research Association) differed from Dr. Colclough as to the relative stabilities of sodium and calcium silicate. The free-energy of formation of sodium silicate (about 40 kg.cal.) was much greater at 1200° C. than that of calcium silicate (about 20 kg.cal.)—*i.e.*, sodium silicate was the more stable. The efficiency of a mixture of lime and soda ash as a desulphurizer was therefore due, he thought, to the sodium oxide reacting with the silica and so enabling the lime to do its work.

Dr. **T. P. Colclough** replied that when limestone was added about twice as much sulphur was removed by the same weight of soda ash. The same applied to agitation. He questioned whether the findings of researches such as the present one were becoming readily available in the works, and suggested that simple working rules should be prepared by the research committees so that the results of their work could be applied in practice.

Mr. **H. Parnham** (General Refractories, Ltd.) described his company's comparative tests on firebricks, unfired stabilized dolomite, 100%-dolomite bricks, and fired and unfired magnesite–chrome bricks in a 3-ton ladle using a 2½-in. lining. The results were:

	Heats		Desulphurization, %		Cost per ton of Metal
	Without Patching	With Patching	Single Ladle	Double Ladle	
Firebrick ...	22	Indefinite	56	66	8¾*d.*
Unfired stabilized dolomite	54	109	62	71	1*s.* 7½*d.*
100%-dolomite brick, fired ...	150	...	61	76	8½*d.*

The magnesite–chrome refractory was taken off after 54 heats on account of serious flaking. The sulphur removal was little better than with firebrick. These tests confirmed that the desulphurization improved with lower silica contents in the refractory. A 4½-in. lining of 100%-dolomite brick in a 25-ton ladle would last up to 500–600 heats.

Mr. **P. Murray** (British Iron and Steel Research Association) thought that the poor results due to skulling obtained with rammed stabilized dolomite,

mentioned by one speaker, were due to cold metal. Magnesite and calcined dolomite were slightly more resistant to attack by soda ash than stabilized dolomite. Tar–dolomite gave better desulphurization than stabilized dolomite bricks, in accordance with theory, but under similar conditions the two materials had the same life, which disagreed with theory. The tendency of calcined dolomite to hydrate ruled out its use for certain types of lining.

Dr. **H. Elliss** (K. & L. Steelfounders and Engineers, Ltd.) said that he used a basic-lined desulphurizing ladle in making steel by the Tropenas process, and had obtained lives of as many as a thousand heats before relining the ladle became necessary. He patched daily, using 10–15 lb. of patching material per ton of metal, and there was no trouble due to skulling unless the metal was cold. He understood that a lithium mineral called spodumene was used for desulphurizing by some firms in the United States of America ; he believed that there were small deposits in Scotland, but did not know their extent.

The **Chairman**, in closing the meeting, referred to the death in a recent motor accident of Dr. A. H. Jay, one of the Members of the Sub-Committee, and expressed the sympathy of all with his family.

WRITTEN REPLY BY THE SUB-COMMITTEE

The Sub-Committee thanked all the contributors to the discussion for their comments. The verbal replies made at the time covered most of the points raised, but certain aspects might be amplified.

It was emphasized that the three Reports were a record of work done, and were in no way final. The tests were made on furnaces supplying metal for process operations, and, because of the danger of interfering with production, experimental conditions that might have yielded more definite data could not be introduced.

In considering differences between results presented in the First and Second Reports account must be taken of variations in the cupola operating conditions. Though the furnace temperatures could not be compared directly, the evidence suggested that the temperature of the metal was lower in the first than in the latter experiments. This, together with the use of the continuous tapping system, might account for the greater dephosphorization and absence of high carbon pick-up in the first tests. In the trials described in the Second Report the weights of the metal and coke charges and height of bed used with the basic lining were exactly similar to those used in normal acid practice. Owing possibly to the use of heavier flux charges and the difficulties of making a fluid slag, the average metal tapping temperature from the basic cupola (1430–1460° C.) was slightly lower than that for an acid furnace (1450–1480° C.). This lower metal-temperature range might have been expected to cause a smaller carbon pick-up in the basic cupola but in practice the pick-up was increased by 0·3–0·5%.

Correspondence on the Paper—

THE APPLICATION OF ELECTROLYTIC POLISHING TO FERROUS METALLOGRAPHY *by H. J. Merchant*

Messieurs **L. Laravoire** and **R. Lellig** (Société des Aciéries de Longwy, Mont-Saint-Martin, Meurthe-et-Moselle, France) wrote : We have read with great interest the paper by Mr. Merchant on the electrolytic polishing of ferrous metals* and also the contribution to the discussion by Mr. J. Pow.† During 1944 we also studied the application of this method of micrographic polishing to various steels, and have been led to very much the same conclusions regarding test conditions as was Mr. Pow, *viz.*, a simple means of holding the specimen, immersion of only the surface to be polished, agitation of the electrolyte, and the use of a rustless-steel cathode.

Our apparatus is represented diagrammatically in Fig. 1. The specimen is fixed as follows : The lower end of the steel-rod support is slightly conical and is cut through longitudinally for about 10 mm. by two saw-cuts on diameters at right angles to one another (*see* Fig. 2) ; a hole slightly larger in diameter than the end of the rod is drilled in the specimen, and the rod is forced into the hole (Fig. 3). In this way good contact between the rod and specimen is assured, and the whole assembly is easily handled.

We used Jacquet's method under the following conditions :

Specimen previously polished on No. 0 emery paper.
Current density, 4–5 amp./sq. dm. (at 60–80 V.).
Temperature, below 30° C.
Duration of electrolysis, 4 min.
Specimen washed, then etched for 1–2 min. in 5% picric acid solution.

By these means we get the same appearance under the microscope as obtained by mechanical polishing for the different types of carbon and low-alloy steel, whether heat-treated or not.

We were led to this procedure during an investigation of the electrolytic polishing conditions which would enable the polished surface to be examined in

* *Journal of The Iron and Steel Institute :* 1947, vol. 155, Feb., pp. 179–194.
† *Journal of The Iron and Steel Institute :* 1947, vol. 156, Aug., pp. 524–526.

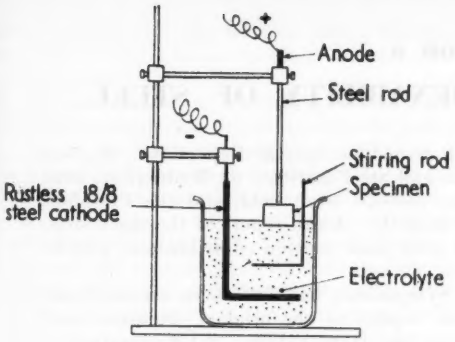


Fig. 1—Diagram of the apparatus

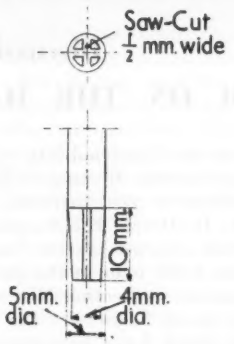


Fig. 2

Fig. 2—End of the rod to hold the specimen (dimensions in millimetres)

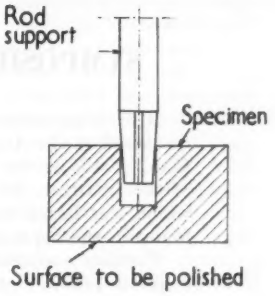
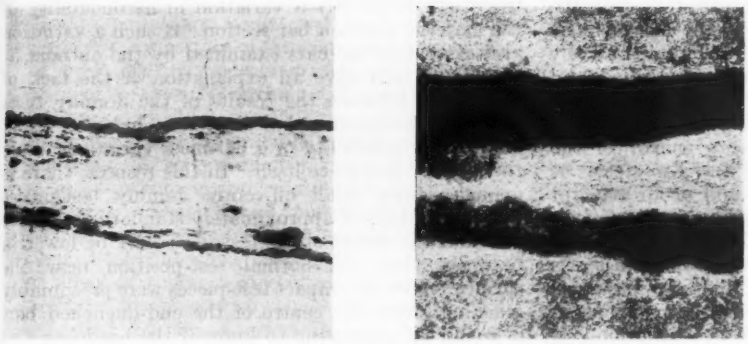


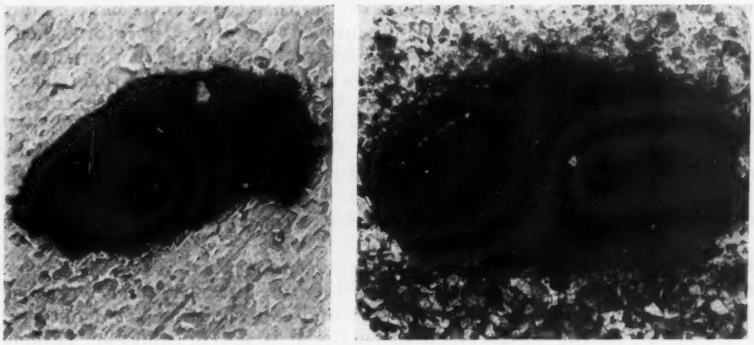
Fig. 3

Fig. 3—Holding the specimen to be polished



(*a*) (*b*)

Fig. 4—Inclusions: (*a*) After mechanical polishing, unetched; (*b*) after electrolytic polishing for 4 min. × 100



(*a*) (*b*)

Fig. 5—Transverse section of a large inclusion: (*a*) After mechanical polishing, unetched; (*b*) after electrolytic polishing for 4 min. × 100

" bas-relief " before any coloration of the constituents set in, with the object of studying non-metallic inclusions, blow-holes, cracks, and other defects. We found it was practically impossible to get a correct electrolytic etch for bas-relief examination; even if the electrolysis is cut down to a very short period (1–2 min.) the inclusions are attacked before the previous emery polishing scratches have disappeared and, further, the metal itself is attacked strongly in the neighbourhood of an inclusion or at the edges of blow-holes (Figs. 4 and 5). German investigators had also observed that electro-negative inclusions were torn out, corroded by the electrolytic polishing. That is one of the disadvantages of electrolytic polishing.

Mr. **H. J. Merchant,** in reply, wrote: I have read with interest the contribution of Messieurs L. Laravoire and R. Lellig on the subject of electrolytic polishing, and must agree that their conclusions are in line with work reported in my paper. The method of holding the specimen by means of a steel rod and a drilled hole, however, suffers from the necessity of having to drill the hole, which may be difficult in some specimens of high hardness.

The note regarding the attack by electrolytic polishing on non-metallic inclusions also confirms my observations of this phenomenon, but some electrolytes vary in the amount of this attack, and the perchloric-acid/alcohol type and those based on nitric acid appear to attack the inclusions less than Jacquet's electrolyte.

Discussion on a
SYMPOSIUM ON THE HARDENABILITY OF STEEL

The Symposium on the Hardenability of Steel, issued as Special Report No. 36, was discussed at the Annual General Meeting of The Iron and Steel Institute on Wednesday, 14th May, 1947, at the Offices of the Institute. Two sessions were held, and the President of the Institute, Dr. C. H. Desch, F.R.S., presided at both. A full report of the discussion, which was based on four selected aspects, together with some written contributions, will be found in the September, 1947, issue of the *Journal*.

Further correspondence, on Section VIE of the Symposium, has since been received and is given below. Also given below are the authors' replies to the original discussion and correspondence, all of which have been approved by the Hardenability Sub-Committee.

FURTHER CORRESPONDENCE

The **Hardenability Sub-Committee** wrote on Section VIE of the Symposium: Mr. Crafts and Mr. Lamont are to be congratulated on the thoroughness with which they have examined the comparatively small samples of British En steels they received, and on the amount of the data they obtained from their examination of those samples.

The work consists primarily of a survey of the hardenability characteristics of the En steels as determined by end-quench tests, and of an attempt to relate the results with the minimum-tensile/size relationship given in B.S.971 (July 1941).

Where the authors had a number of different steels representing a specification they found appreciable spread in the end-quench test results, some of which can probably be accounted for by variations of composition both within the limits of the elements specified and in those elements unavoidably present but not prescribed by the specification. By averaging the Jominy hardenability curves for each En type, however, they show that the degree of hardenability of different steels recommended for the same tensile strength does not vary greatly and that there is a progressive increase in Jominy hardenability with increase in minimum tensile strength required for 4-in. ruling section. It is gratifying that this result should be observed but it would have been very surprising had it been otherwise, as the En steels had largely been selected as a direct result of experience and actual mechanical tests from steels in the hardened and tempered condition.

Incidentally, it should be pointed out that the test position for 2½- and 4-in. ruling sections is at the middle of the radius and not at the centre. Consequently, to appraise correctly the En steels, all the experimental work concerning these sizes should have been related to the specified test-position and not to the centres of the bars.

Turning to the correlation of tempered Jominy data with tests on heat-treated bars, it is noted that the figures presented show agreement in the smaller bar sizes, i.e., 0·45 in. square and 1 in. in dia., but in the larger sizes, 2·5 and 4 in. in dia., the agreement is not so good, the difference increasing with increasing size of the bar. It is stated, in the discussion of the hardness data, that this trend of results is believed to be due to some air-hardening effect at the surface of the Jominy test-piece. In this connection, it is worth noting that the Sub-Committee found that there was frequently a variation in hardenability of the material across a bar section. If such a variation also existed in the bars examined by the authors, it would not only give an explanation of the lack of correlation between the results of the Jominy tests and the corresponding bar diameters, but also would suggest the possibility of a hardness variation across the Jominy test-piece itself. In this respect, there is evidence from small off-centre Jominy test-pieces taken from bars of approximately standard test-piece size that the centre of the test-piece may be lower in hardness than the normal test-position near the surface. Since the impact test-pieces were presumably machined from the centre of the end-quenched bar, it would be interesting to know if the hardnesses at the selected positions of the notch were lower than those recorded, both in the as-quenched and as-tempered conditions, and if the effect of the lower hardness on the impact value was taken into account.

It was also observed that the authors have used a single quenching-intensity value ($h = 0{\cdot}7$) throughout their work. This contrasts with the Sub-Committee's findings that it was impossible to obtain a satisfactory correlation between calculated and experimentally observed hardness values if a single value of h was used. Again the Sub-Committee considered this to be due, in large part, to the heterogeneity factor. On the other hand, the effect of using different intensity values is less marked when applied to the tempered condition.

In general, it is agreed that there is a *broad* correlation in hardness between hardened and tempered Jominy test-pieces and corresponding bar diameters, even when the material is not of uniform hardenability. That the correlation is fairly reasonable under these conditions is due to the fact that tempering irons out the differences occurring in the quenched specimen. In considering the question of this correlation on the basis of microstructure, due note should also be taken of the hardenability variations, since these, if present, can result in fairly wide differences in as-quenched hardness and hence affect the microstructure for the same cooling rate. Thus simply translating a 100% martensite position on a Jominy bar to a bar diameter, as the authors have done

(p. 289 of the Symposium), without taking the heterogeneity factor into account is likely to give rise to appreciable errors.

The authors' method of calculating tensile strength mainly from composition is interesting and deserves study. Until, however, hardenability variations, say, within a single bar, can be controlled or at least taken into account, such methods, even if incorrect, are liable to lead the user astray, particularly if tempering temperatures lower than 500–550° C. are used.

In general, the authors' results obtained from their correlation studies are not at variance with some of the Principal Conclusions of the Hardenability Sub-Committee, *e.g.*, Conclusions 7, 10, 11 (pp. 414 and 415).

AUTHORS' REPLIES

Dr. **W. Steven,** in reply to the discussion on "*The Reproducibility of End-Quench Curves*," wrote : Mr. Service queries whether steel of commercial origin is the most suitable raw material for investigation. Undoubtedly, for certain of the more academic phases of the work, specially prepared melts of high purity would be preferable. Nevertheless, it must be recalled that it was originally hoped that the end-quench test would prove to be a valuable routine production-control test, and the general objective of the work was to assess its usefulness and reliability in testing commercial steel. The quality of those steels tested was, as far as could be judged by normal macro and mechanical testing, wholly satisfactory.

The effect of rolling temperature on hardenability has not been investigated by the Sub-Committee and, as suggested by Mr. Service, it may have some influence. There is, however, little evidence to suggest that this variable is responsible for the bulk of the variations revealed in the Symposium. For example, the hardenability pattern observed on transverse sections would be difficult to explain in terms of rolling temperature.

As indicated on page 133, bars tested by the Sub-Committee were maintained at the quenching temperature for 1 hr. per inch of diameter before quenching. This is considered to be more than adequate to eliminate the effect referred to by Mr. Service.

Future work on hardenability must inevitably be extended to larger bar sizes, but the end-quench test, with which the Symposium is primarily concerned, is not capable of yielding information on oil-quenched bars of larger diameter than those tested.

The results of the more recent work reported by Mr. Bucknall are extremely interesting and supply further useful confirmation of certain of the conclusions reached by the Sub-Committee. As Mr. Bucknall remarks, the correlation of ingot structures and the hardenability patterns observed in bars and billets deserves early attention.

Dr. Whiteley's kind remarks are appreciated. Although there are very few references to **S**-curves in the Symposium, the Hardenability Sub-Committee is fully aware of the close link between transformation characteristics and hardenability, and this aspect of the subject will certainly receive close attention in the near future. On the other hand, the difficulty of applying isothermal-transformation diagrams to continuous-cooling conditions must not be overlooked.

Mr. Burton suggests that the "surface material" of higher hardenability probably corresponds to the columnar material. This possibility has been considered but, on the basis of the evidence available at the time the Symposium was prepared, the Sub-Committee was unable to reach a definite conclusion. More recent evidence on this aspect of the work is covered by Mr. Allsop's contribution.

In reply to Mr. Burton's further remarks, some information on hardenability variations existing within billets from the top, middle, and bottom of ingots is given in Part III of Section VIB. Much more information on this aspect of the problem, and also on the relative influence of forging and rolling is, nevertheless, still required.

The contribution of Dr. Wrażej is welcomed. If possible the analysis of some of the steels will be extended to include gas contents.

Mr. Brown criticizes the fact that the specification in Section III does not limit the size or form of the material from which the oil-quenched test-specimen is machined. This omission was quite deliberate and is fully justified by the transverse and longitudinal hardenability variations which the Sub-Committee has shown to exist within steel bars. Any attempt to determine the hardenability of a batch of steel from a limited number of tests must be regarded as a compromise and the test-positions giving the most satisfactory compromise will vary depending on the application for which the steel is intended. For many applications, as Mr. Brown suggests, a sample machined from a $1\frac{1}{2}$-in. dia. wrought bar will be satisfactory, but for others it might be preferable to machine the test-specimen from an alternative position, *e.g.*, the mid-radius of a larger bar.

Mr. **J. Glen,** in reply to the discussion on "*The Influence of Chemical Composition on Hardenability*," wrote : Mr. J. Woolman has emphasized that many factors, apart from grain-size and composition, may influence the hardenability, and Dr. N. P. Allen suggests that "we should retrace our steps and study separately the effects of the alloying elements on each of the reactions which are important in this connection," although he does admit that this may take a very long time. Until such data are available, the practical metallurgist must approach the subject in a more or less empirical manner by choosing a reasonably simple set of experimental conditions.

Thus Mr. E. H. Bucknall is quite correct in stating that there is nothing very wonderful about the criterion of hardenability used, and he considers it to be over-emphasized. It is unfortunate that such an impression was made, because the sole reason of the emphasis was to establish clearly the arbitrary nature of the criterion used. Mr. Bucknall suggests that the determination of the isothermal characteristics of steel can be regarded as a more precisely discerning hardenability measurement. It is difficult to see in what way the maximum transformation velocity or any other criterion based on **S**-curves can be correlated in a simple manner with the hardness obtained under continuous-cooling conditions.

It is interesting to note that Mr. Bucknall finds that boron-treated steels are particularly prone to hardness variations across the section. There is no doubt, however, that the addition of boron does greatly increase the hardenability even at the centre of a section which does show a hardenability variation.

Dr. H. O'Neill and Mr. J. Dearden (in a written contribution) consider Conclusions 1 and 2 (page 395) to be unjustified because the multiplying effect is purely an arithmetical and not a metallurgical effect; but since these conclusions refer solely to the variation of the effect, it is difficult to realize in what way they are not correct. In any case, the variation of hardenability as defined by the multiplying effect or any other method can be due to nothing else but a metallurgical effect.

If hardenability is defined as the depth of hardening in a standard quench which will give a particular percentage of martensite, it does not take any cognisance of the actual hardness obtained in any particular steel with that percentage of martensite. Thus, in effect, the hardenability of a particular steel is represented by that particular cooling velocity which gives the required percentage of martensite.

On the other hand the " carbon hardenability equivalent " (C.E.) is the maximum hardness obtainable in a standard weld test, *i.e.*, standard cooling conditions. It is thus to be expected that the C.E. would be related to the hardness at that particular distance from the quenched end of a Jominy test which approximates most closely to the cooling conditions obtained in the standard weld test. Unfortunately space did not permit the reproduction of the many Jominy tests obtained, so that the work is not of much help to Dr. O'Neill and Mr. Dearden.

These contributors are also correct in suggesting that the tendency for a hump to form in the Jominy curve is present in many other steels.

Thanks must also be extended to Mr. T. M. Service, Dr. L. K. Janiček and Dr. R. Pospíšil, and Lieut.-Col. T. B. Biernacki for the information which they have submitted in the discussion.

Mr. **T. F. Russell,** in reply to the discussion on " *The Prediction of Hardness and Transformation Ranges from End-Quench Hardenability Curves,*" wrote: I should like to thank Dr. Allen and Mr. Bucknall for taking part in the discussion, and particularly Dr. Allen for his kind personal remarks.

Dr. Allen sums up the present position very well indeed in his last paragraph. I fully agree that there is a case against over-elaboration of the mathematical side of the problem, but I agree not because of the recital of the numerous difficulties connected with the work, of which the Sub-Committee was only too well aware, but because the work already done by the Sub-Committee proves it to be so. It was necessary to make the mathematical approach before we could decide if there was anything in it.

In his sixth paragraph, Dr. Allen sets out what he says are the fundamental assumptions on which the attempted correlation between the results of a Jominy test and a hardness traverse of a quenched bar is based, and then proceeds with such lively criticisms of them that the lay reader may be convinced that the actual assumptions made are totally untenable. In order to dispel any such impression I shall deal with Dr. Allen's remarks in detail.

Dr. Allen says: " The first assumption is that a quenching intensity can be assigned to a quenching medium which is, within limits, the same for every steel and the same for every size of bar."

This statement is correct, provided that it is understood that " within limits " applies to the chemical composition of the steels and the bar sizes. The quenching intensity, as defined by $h = C/k$, is not assumed to be a constant characteristic of the quenching medium alone but of the medium *and* the steel.

To estimate the value of h for one medium and one steel by the particular process fully described in the report, it is necessary to know something about the cooling curves (in our case the half-temperature times) at points along the Jominy bar during the course of the test. Having estimated this value of h the Sub-Committee then proceeded to examine to what extent the half-temperature times determined on the reference Jominy bar (Fig. 20) could be used to forecast the hardness traverse of bars of different sizes of the reference steel and the hardness traverse of other steels, dissimilar in composition but *similar in their having approximately the same half-temperature times along the Jominy bar* (*see* Fig. 21). No surprise therefore need be felt that " the correlation is as good as indeed it is."

Dr. Allen also says: " the second (assumption) is that the half-temperature time is an adequate statement of the cooling rate at the point in question."

I should like to make it quite clear that the Sub-Committee makes no claim to originality in the choice of half-temperature time as a criterion of rate of cooling. In America, at the time our work commenced, the cooling rate at 1300° F. had been more or less abandoned in favour of the half-temperature time, and the published results were so promising that the Sub-Committee followed this lead. The difficulties in defining quantitatively the expression " cooling at the same rate " is fully dealt with in Section IVA.

There is little I can add to this beyond saying that from both a mathematical and a metallurgical point of view I profoundly disagree with Dr. Allen when he says that we know *quite definitely* that we are wrong in taking the half-temperature time as a criterion of cooling rate.

In the first place it is, of course, common knowledge, particularly to those metallurgists who, like some members of the Sub-Committee, have spent years studying the isothermal characteristics of steels, that when a steel hardens it transforms in some range usually lower than the half-temperature range.

It can also be accepted, with certain important reservations, that in general the hardness will depend on the time taken by the steel to pass through the lower-temperature range or ranges.

Secondly, we are interested primarily in the depth to which a steel will harden on quenching, alternatively in the size of the unhardened core. Now, before any steel will begin to show any appreciable hardening due to the formation of the lower-temperature products, the speed of cooling through the " pearlitic "

range, *i.e.*, the upper range, must reach the pre-critical speed, and near maximum hardness is not attained until the critical speed is reached. Still further increases in cooling speeds have only minor effects on the hardness until the cooling speed becomes so great—the cooled section being so thin—that true martensite is formed. So that whether a steel will harden at all depends *primarily on the rate at which it passes through the upper range of temperature* and not on the speed at which it passes through the lower range. It therefore seems logical to take some quantitative measure of the first half of the cooling curve, rather than the lower half, if we expect to find some correlation between the Jominy tests and the traverse hardness tests. My own opinion is that it will be a long time before we find anything better than the half-temperature times as criteria of cooling curves in the upper-temperature range.

Dr. Allen's third point is the assumed constancy of thermal constants with temperature and the ignoring of the effect of latent heat when calculating cooling curves.

This will always be a valid point in adverse criticisms of the use of the tables which I published in 1936. I can only again assure such people that the tables are in constant use for the very good practical purpose of predicting cooling curves; perhaps not with academic accuracy, but with that degree of accuracy which may make all the difference between a successful and an unsuccessful heat-treating operation. I attribute this successful application of the tables to three main reasons:

(*a*) We are usually concerned only with the first part of the curve on cooling from the forging temperature or austenitizing temperature, *e.g.*, half-temperature times in hardenability investigations.

(*b*) Work at the National Physical Laboratory has shown that there is less variation of thermal conductivity in the upper ranges of temperature than in the lower ranges.

(*c*) We are usually concerned with rates of cooling of masses of those steels which have an austenite sufficiently stable in the "pearlite" range that transformation does not take place until the intermediate stage is reached. Most of the steels dealt with by the Hardenability Sub-Committee fall in this category.

Mr. Bucknall has redrawn in Figs. B and C theoretical curves based on half-temperature times similar to those published by Lamont (*see* reference 163, page 426, and Fig. 262 of the Symposium), and he points out that within the range of useful interpretation of the Jominy test there is an approximately linear relationship.

An approximately linear relationship will also be found when the curves are plotted on the basis of equal rates of cooling at 1300° F., and as the straight lines on both diagrams pass through the origin it is inevitable that there will be coincidence for some value of h. It is purely fortuitous that the value of h is about 1·0; this has no significance whatever.

I do not know of anything written in the Symposium which justifies Mr. Bucknall's statement that "the agreement between those points and an imaginary curve for $h = 1{\cdot}0$ is much closer than Mr. Russell's theoretical considerations might have led one to expect."

Mr. Manning's suggestion that the lack of correlation between the actual hardness traverse and that predicted from a Jominy test is due to pressure effects on quenching, is interesting, but I prefer to withhold comment until the theory is elaborated.

In their written contribution, Pumphrey and Jones very rightly emphasize the importance of practical testing after a suitable selection of steels has been made from Jominy tests. Nevertheless, the test has undoubtedly come to stay and the more we know about its capabilities and limitations the better.

Both Mr. Williamson and I are grateful to Dr. Jones for his explanation and proposed correction for the sudden initial surface-temperature drop on removing a Jominy bar from the furnace.

Mr. **W. E. Bardgett,** in reply to the discussion on "*The Influence of Hardenability on Mechanical Properties*," wrote: Mr. Bull makes apt reference to the aim of the work carried out by the Sub-Committee. The point he raises regarding the deficiency of the test being rather that of failure to predict certain mechanical properties than of failure to measure hardenability of a cast, is well appreciated, but the test should primarily be a reliable measure of hardenability, and in this respect it has considerable limitations owing to the nature of the material being tested. Mr. Bull's comments on exchange of hardenability for toughness appear to be over-generalized. When speaking of different casts, one does not find consistency as regards the relation between hardenability and toughness owing to inherent cast variables which affect toughness, this inconsistency apparently becoming more marked at higher tensile ranges. One can sympathize with Mr. Bull's desire for a ready means of assessing the properties of a steel, and his references to the transverse tests are most interesting. In the first of these the test is made in such a way as to provide results related to the properties required of material for pressure vessels, and therefore, being more direct in application than a Jominy test, is certain to be of more value. The second test, used by gear makers, is again more directly applicable than a Jominy test and should give more useful results, although an impact test alone would be insufficient.

It is interesting to note that Mr. Stokeld has used a similar test and achieved considerable success with it as a measure of the response of a steel to heat-treatment for particular applications.

The steels referred to in Section VIᴅ were entirely transformed at 400–450° C. and not partially transformed as suggested by Mr. Bull. This treatment resulted in partial hardening and provided a comparison with the same material fully hardened, both being subsequently tempered. This method of comparison could not be applied to all steels, its application depending on the transformation characteristics of the steels.

The point raised by Mr. Bull regarding temper-brittleness, to which the late Dr. Swinden referred in his preface, was one which was always in the minds

of the Sub-Committee, and due consideration was given to this in carrying out the tests.

Mr. Stokeld has related some interesting practical experiences which firmly support the findings of the Sub-Committee as regards the limitations of the hardenability test in predicting satisfactory mechanical properties. It is rather surprising, however, to find that a surface hardness of 460–520 V.P.N. was obtained in one lot of material having a 1-in. ruling section when water-quenched, and 700 V.P.N. in another lot, although both gave similar Jominy curves. The only explanation for this would appear to be that the position of hardness tests on the Jominy specimens and on the forgings did not correspond equally with respect to the cross-section of the original ingots.

Mr. Bucknall is probably correct in suggesting that in examining a wide variety of steels for hardenability, the Jominy test would be useful in eliminating those materials which are clearly "out of court," but if such a series were being examined, not from the aspect of general response to hardening applicable to all sizes, but to one particular size and for one particular purpose, then Mr. Stokeld's test would be the one to choose. As regards finding out the fundamentals of mechanical properties of alloy steels, it is agreed that the field between the Jominy test and transformation measurements is an extremely important one which no doubt will receive the attention which it warrants.

It is hoped that the results of the work being carried out by the Mond Nickel Co., Ltd., relating tensile strength and tempering temperature for different initial hardnesses, will be published, as it is of very great importance in contributing to our appreciation of the problem.

Lieut.-Col. T. B. Biernacki rightly points out that the hardenability test is strictly limited to hardness, but there is a fairly definite relation between the latter and tensile strength. However, the object of the Sub-Committee's work was to determine the extent of the possible application of the test as a measure of the mechanical properties. As the results in the report have shown, a single test cannot confidently be applied to measure the transverse hardness of quenched bars and is therefore limited as a means of determining the heat-treatment required of a given steel.

The Jominy test should be directly applicable to the problem of hardening of tools referred to by Mr. Hannah, although careful selection of the test-piece to correspond to the zone of hardening of the tool would have to be made.

The problem of diffusion, referred to by Mr. Preece, is of fundamental importance and will no doubt receive the attention of those who continue this work.

It is particularly interesting to learn that Mr. Bavister successfully applied the Jominy test to reveal the subtle distinctions in hardenability between specifications En 34, En 35*A* and En 35*B*, which differ only in the range of carbon content.

On the basis of the results given in the Symposium, however, which show that appreciable variations in hardenability between the outside and the centre of a bar may arise, and also on account of the serious overriding factors to which Mr. Bavister himself refers, it would hardly be expected that the distinctions would be very precise and reliable.

Mr. **Crafts** and Mr. **Lamont,** in reply to the correspondence submitted on behalf of the Hardenability Sub-Committee by Dr. W. Steven, wrote: Dr. Steven's discussion of our paper is greatly appreciated. Since the paper was submitted in 1944, additional information has made it possible to improve the interpretation of some of the data and to review the conclusions from a different viewpoint. The work was originally started to facilitate correlation in Canada of American and British steel specifications, and the report was ultimately submitted for use in the Symposium at a time when there was an urgent need to utilize more effectively the inadequate supplies of critical alloys. Subsequent review of the recent progress in the heat-treatment of steel has emphasized the deficiencies of theory and application, but does not appear either to have invalidated the basic conception or to have obscured the practical utility.

We are glad to have the opportunity to correct our statement that there is a discrepancy between the tempered Jominy and overall quenched bars in the larger ($2\frac{1}{2}$- and 4-in.) sections. Subsequent study* has shown that the observed differences resulted from the longer tempering times used for the heavier sections. It was found that estimates could be made within limits of 5 Rockwell "C" or 7 tons/sq. in. Hardness determinations on Izod specimens cut from the centres of tempered Jominy specimens revealed no significant difference from the surface hardness. The use of a single value of $h = 0{\cdot}7$ to represent the severity of our oil-quench is an over-simplification, but it was justified by the test data.

Dr. Steven has questioned the use of 100% martensite as a critical index of hardenability on account of the heterogeneity of the steel. Aside from the question of heterogeneity, the use of 100% martensite as a criterion of hardenability, instead of 50% martensite or some other critical level of hardening, has a real and practical significance. Several workers have found that ductility and yield strength for a given tensile strength attain a maximum if the steel is quenched to martensite prior to tempering. Recent work by the authors† on the relation between hardenability, hardness, and Izod impact strength, has also confirmed that steels quenched to less than 100% martensite have less than maximum impact strength at a given hardness level. The 100% martensite criterion, therefore, represents a fairly well fixed level of optimum combinations of properties by which incompletely hardened steel may be appraised. Furthermore, the degree of deterioration of impact strength with slack quenching depends on the character of the steel. In alloy steels the impact strength is harmed relatively little by the first introduction of non-martensitic constituents. However, in those shallow-hardening steels that tend to form massive ferrite or pearlite as the initial non-martensitic constituent, the impact strength is lowered abruptly and seriously at the first indication of incomplete hardening.

The significance of heterogeneity, then, depends on the degree to which segregation inhibits the development of 100% martensite in quenching and the degree to which the resulting properties are impaired. Study of the gradation of martensite from surface to centre

* W. Crafts and J. L. Lamont, *American Institute of Mining and Metallurgical Engineers, Metals Technology*, 1946, Sept., Technical Publication No. 2036.

† W. Crafts and J. L. Lamont, *American Institute of Mining and Metallurgical Engineers, Metals Technology*, 1947, Feb., Technical Publication No. 2134.

has indicated that the gradient is independent of carbon and alloy contents but is affected by "deoxidizers." In silicon- and aluminium-killed steels it is necessary to have more than about 75% martensite at the centre to obtain 100% martensite at the surface, where optimum quality is required. Even badly segregated areas would, therefore, be expected to be predominantly martensitic, if the hardenability of the homogeneous steel is adequate. Thus, in alloy steels that can tolerate sub-martensitic structures, normal heterogeneity should not be expected to produce a critical loss of properties. The serviceability of alloy steels with commercial degrees of segregation tends to confirm this analysis of the significance of 100% martensite as a criterion of hardenability.

We agree with Dr. Steven that the Jominy test and hardenability calculations have shown good tendencies toward agreement with tests of overall quenched sections, but that greater accuracy would be desirable. With a few exceptions, the probable degree of error has been recognized and is surprisingly small in view of our lack of understanding of quenching and hardening. In the last decade the effort to apply quantitative control to the heat-treatment of steel has resulted in a relatively simple pattern for prediction of the behaviour of idealized steel in an idealized quench in order to develop specific mechanical properties. Such obvious over-simplification has been necessary and desirable in order to establish a foundation. Much additional work is required on all phases of the problem, and the importance of segregation has been brought out forcibly in this Symposium. In spite of its deficiencies this first approximation of the hardenability pattern has been found to have a utility of immediate practical value, and it provides a basis for developing more refined calculation and improved practices.

Correspondence on the Paper—

DEFORMATION OF METALS DURING SINGLE AND REPEATED TENSILE IMPACT* *by J. A. Pope*

Mr. **A. C. Vivian** (London) wrote : Dr. Pope draws only a negative conclusion from the test data graphically portrayed in Fig. 28. That does less than justice to his work, for the conclusions to be drawn from Fig. 28 are, in the writer's opinion, of the greatest importance to practical engineering.

The main burden of the paper is to draw attention to the different effects of static and high-speed loading, respectively on the tensile character of steel. But Dr. Pope confines his paper almost entirely to the development of yield at various loading speeds and to necking, which are doubtless of great academic interest but not so much of practical concern. The yield point is not by any means the important tensile characteristic of steel compared with its effective ductility ; that is to say the amount which steel will stretch with a rising load before it begins to neck to failure. Steel structures are commonly designed with a factor of safety of 3 or 4 and when a failure occurs, which is the important thing to avoid from a practical point of view, it occurs because at some point the steel has been stretched to the limit of its effective ductility, while the stress in the remainder of the structure may still be well below the yield point. It follows, therefore, that steel with considerable effective ductility carries a far greater insurance against failure than a steel with a small effective ductility, however high the initial yield point of the steel may be.

Figure 28 enables the effective ductility of the steel tested to be determined (*a*) under "static" loading, *i.e.*, ordinary laboratory tensile-test speed, and (*b*) under "impact," *i.e.*, high-speed application of load. It is notable, without calculation but by merely glancing at the Figure, that the effective ductility of that particular steel is seen to be greater at high-speed loading than under slow speed.

The type of curve portrayed in Fig. 28 is well known. The writer has examined many such curves, mostly unpublished. The first which were published, so far as the writer is aware, were contributed by the late Mr. E. G. Izod to the discussion of the late Professor W. C. Unwin's paper entitled, "Tensile Tests of Mild Steel, and the Relation of Elongation to the Size of Test Bar."† Curiously enough they evoked no comment, but they were fundamental to Unwin's main thesis that if only the "general elongation" (effective ductility now called) were measured, the difficulty of comparing the elongation of different test bars would disappear.

Each curve is asymptotic to a line parallel with the base line (the gauge-length axis, or it may be the gauge length divided by diameter axis). The height of that line measured to the scale of the vertical axis (the percentage elongation) is the effective ductility of the steel at the given rate of loading.

The equation to each curve is of the form :

$$\text{Percentage elongation} = \left(S + \frac{kd}{L}\right)100,$$

and the values of the constants for the two curves shown in Fig. 28 are :

$$\text{Elongation (Static), } \% = (0{\cdot}24 + 0{\cdot}08/L)100 \ldots (1)$$
$$\text{,, (Impact), } \% = (0{\cdot}27 + 0{\cdot}04/L)100 \ldots (2)$$

where $d = 0{\cdot}225$ in., $k = 0{\cdot}35$ for static loading and $0{\cdot}18$ for impact. Figure A, attached hereto, shows these two calculated curves superimposed on the curves given in Pope's Fig. 28. It may be objected that the calculated curves do not exactly coincide with the measured curves.

Above the horizontal asymptotic lines the objection is irrelevant because the amount which a bar of steel will stretch after it has commenced necking to failure is of no practical significance. That characteristic of steel to draw down before failure is better measured by its R.A., % (percentage reduction in area).

As a point of academic interest the discrepancies between the calculated and measured curves above the asymptotes can fairly be attributed to the difficulties of measurement on short gauge lengths and to end effects, and to the particular gauge length not including the whole of the neck.

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, pp. 31–54.

† W. C. Unwin, *Proceedings of the Institution of Civil Engineers*, 1903, vol. 155, pp. 277–280.

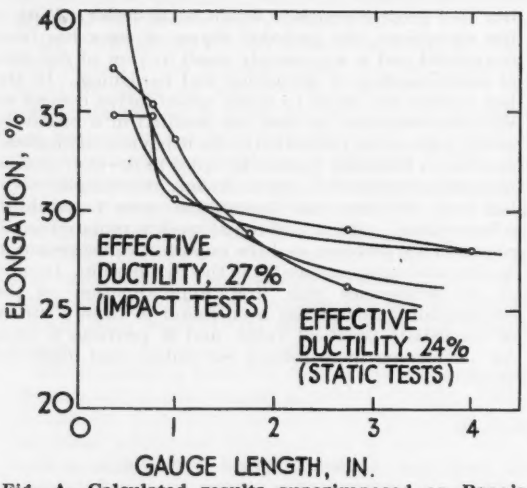


Fig. A—Calculated results superimposed on Pope's test results showing the effect of gauge length on elongation during impact and static tests

Near the horizontal asymptotic lines the divergencies are not important, though by re-calculating the constants in equations (1) and (2) previously, the lines might be brought a little more closely into coincidence. But it is not very important because the effective ductility of mild-steel bars cut from the same plate and in the same direction of rolling may vary by 1 or 2%. The test data published by Unwin in the paper previously referred to bring this out very clearly (*see also* ref. 3). The important point is whether the effective ductility is, for example, 10% or 20%, not whether it is 20% or 22%.

It should perhaps be pointed out that in the equations given previously it is the "S" term which, multiplied by 100, is the percentage of effective ductility and which is, to the appropriate scale, the height of the horizontal asymptotic line.

It is a fact of great practical importance that a nominal stress/strain line can be constructed knowing the effective ductility and given the U.T.S. and R.A., %. It is of even greater practical significance that the transverse notch-bar value is primarily a function, though a somewhat complicated one, of the effective ductility. Also, the tensile-impact value of a steel bar can be deduced from the effective ductility, U.T.S., and R.A., %. In each case the nominal stress/strain line must be obtained at the same speed of loading as for the notched-bar transverse or tensile-impact test, and that presents a difficulty in regard to the measurement under high-speed loading of U.T.S., *i.e.*, maximum stress.

The writer cannot, in the limitations of space for a contribution to discussion of a paper, set out the detailed exposition of the foregoing statements that effective ductility, U.T.S., and R.A., %, all measured at the requisite testing speed, are the basic data for determining the notch-bar transverse and tensile-impact values of a particular steel. The writer has, however, worked out these fundamentally important relations in a previous paper.[1] An account of the inter-relation between effective ductility, U.T.S., and R.A., %, and the nominal stress/strain line is contained in another paper,[2] and a concise summary of the inter-relation between the foregoing, and the transverse notch-bar value is set out in a further paper as yet unpublished. A detailed analysis of Unwin's tests on the percentage of elongation of steel is contained in a recent paper[3] by the writer.

Two points are of particular importance. The first is that yield point (drop of the beam) is unimportant or even is entirely irrelevant to the notch-bar value and the tensile-impact value of steel. The other is that whereas, previously, the writer had been obliged to assume that the effective ductility of steel is different at different loading speeds in order to effect his correlations between the tensile test and the notched-bar test, Dr. Pope has now provided the necessary experimental proof with the test data recorded in his Fig. 28.

There still remains the question of the rise of the U.T.S. at high loading speeds. Clark and Dätwyler[4] show mild steel under dynamic loading to have a maximum stress 50% higher. It is possible that with a steel of the character to which Fig. 28 refers, the U.T.S. at high-speed loading may rise as much as 50% above the static U.T.S. value. This is controversial yet it would not appear to be difficult to measure together with the effective ductility and reduction in area.

The fact of the considerable rise of U.T.S. at high-speed loading is, however, already proven by the test measurements of tensile impact published by Professor Warnock and Dr. Pope.[5] This conclusion follows by adding up the area under the load/extension curve to the appropriate scales. Although stress/strain (or load/extension) curves were not given, the area was determined by the tensile-impact measurement. Only by making the U.T.S. at high speed considerably greater than the "static" U.T.S. value could the area under the load/extension curve be equivalent to the tensile impact value. That might be described as a triumph of arithmetic over mathematical theory. Dr. Pope is to be thanked for providing the test data required to establish these facts.

References

1. A. C. VIVIAN : "Plasticity," 1945. Unpublished copy available at the libraries of the Institution of Civil Engineers and the Institution of Structural Engineers.
2. A. C. VIVIAN : *Structural Engineer*, 1947, vol. 25, pp. 165–178.
3. A. C. VIVIAN : *Journal of the Institution of Civil Engineers*, 1947, vol. 29, pp. 138–153.
4. D. S. CLARK and G. DÄTWYLER : *Proceedings of the American Society for Testing Materials*, 1938, vol. 38, pp. 98–106.
5. F. V. WARNOCK and J. A. POPE : *Proceedings of the Institution of Mechanical Engineers*, 1947, Sept., War Emergency Issue No. 26.

AUTHOR'S REPLY

Dr. **J. A. Pope** wrote : Mr. Vivian attaches rather greater importance to Fig. 28, in my paper, than I feel is justified, and draws from it conclusions which, to me, seem to be based on assumptions which are completely at variance with the experimental evidence given in the rest of the paper.

Mr. Vivian states that I "confine my paper almost entirely to yield at various loading speeds and necking." Surely this is incorrect ! Figures 7, 16, 17, 18, 22, 23, and 24 in the paper give the whole process of deformation from the instant of yield to the moment of fracture. I am wondering whether the real purpose of the paper has been fully appreciated. The main object was to investigate the deformation of metals during tensile impact. The paper gives experimental evidence which proves beyond doubt that the mode of deformation during impact is fundamentally different from that in a static test.

Deformation during the early stages of a static test is uniform along the specimen, the specimen increasing in length and decreasing in cross-sectional area, until a strain S is reached when, if the specimen is extended

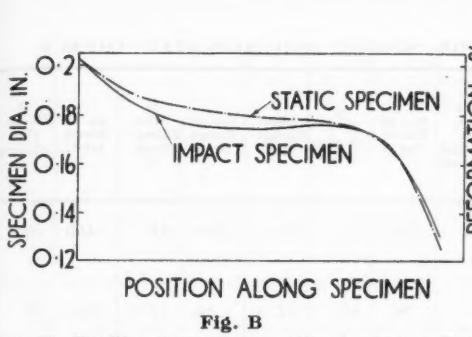


Fig. B

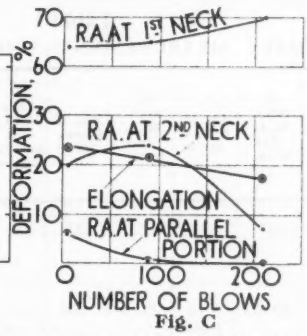


Fig. C

Fig. B—Profile of specimens after impact and static tests. Original diameter, 0·203 in.; gauge length, 0·75 in.

Fig. C—Variation of ductility with number of blows. Material: Lowmoor iron, as received

further, the loss in strength due to the reduction in area, produced by the additional extension, is greater than the gain in strength by work-hardening. Thus when this extra extension occurs at a particular section, that section becomes weaker than the rest of the specimen, and deformation is localized at that section, producing a neck in the specimen.

If:

P = load on specimen
A_o = original area
A_ϵ = area at strain ϵ
ϵ = strain $= \left(\frac{A_o - A_\epsilon}{A_\epsilon}\right)$
S = strain at which necking commences $= \left(\frac{A_o - A_s}{A_s}\right)$
σ = true stress $\frac{P}{A_\epsilon}$,

then it can be shown that when:

$$\frac{\sigma}{1+\epsilon} = \frac{\delta\sigma}{\delta\epsilon}, \quad \epsilon = S, \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

i.e., the general strain along the specimen when necking commences (called " effective ductility " by Mr. Vivian). Now $\frac{\delta\sigma}{\delta\epsilon}$ is the slope of the stress/strain diagram, and therefore " effective ductility " in a static test depends upon the shape of this diagram only. With steels which age-harden, the rate of loading during a static test, *i.e.*, weeks or minutes to fracture, affect the shape of this diagram and therefore the effective ductility, but for given conditions of loading the effective ductility is a function of the metal only.

In a tensile test the total extension is made up of two parts; (*a*) the general extension over the whole gauge length before necking takes place (denoted by A, say), and (*b*) the local extension which takes place in the neck (denoted by B).

Thus the total extension $= A + B$,

and $A = SL$, where S = general strain when necking is about to commence, and L = gauge length.

Now if it is assumed that B is proportional to the diameter of the specimen only (an assumption which is approximately correct), we get:

$$B = Kd,$$

where d = diameter of specimen, K = constant. Thus total extension $= SL + Kd$, and the percentage of elongation:

$$= \left(S + \frac{Kd}{L}\right)\frac{100}{1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equation (2) is the equation given by Mr. Vivian and there is no doubt that it is applicable to static tension tests, and has a fundamental significance.

During tensile impact, however, permanent deformation is initiated with the formation of two necks simultaneously, one at each end of the specimen. These necks gradually spread along the specimen until they meet, the specimen becoming approximately parallel. Finally a third neck is formed at the centre of the gauge length which leads to fracture.

Thus the "effective ductility" (elongation before the final neck is formed) in this case depends upon size of the initial two necks, the shape of the plastic waves and the distance they travel before meeting. The initial size of the neck depends upon the velocity and energy of the impact, while the shape of the plastic wave depends upon the work-hardening properties of the metal and the velocity of impact (equation 7 in the paper). In the experiments represented by Fig. 28, all of these factors were kept constant, the gauge length being the only variable. This, however, affects the distance travelled by the plastic waves before they meet.

Thus for impact we have total extension $= A + B$,

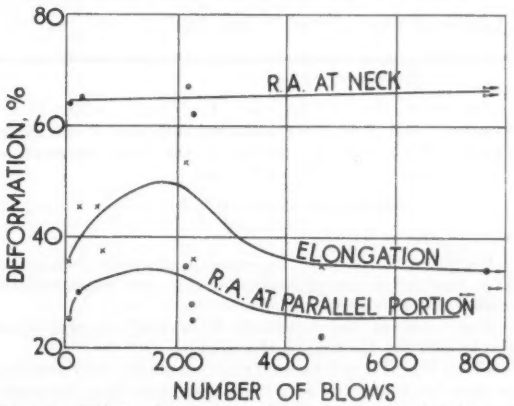


Fig. D—Effect of number of blows on the ductility of normalized mild steel

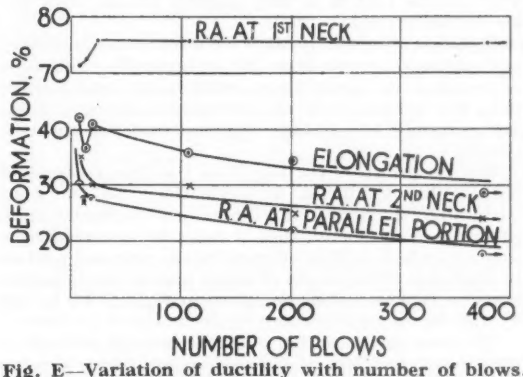


Fig. E—Variation of ductility with number of blows. Material, annealed 60/40 brass

Table I

VARIATIONS IN DUCTILITY MEASUREMENTS FOR SINGLE AND REPEATED IMPACT

Metal	A Max. R.A. (1st neck), %	No. of Blows for A	B Min. R.A. (1st neck), %	No. of Blows for B	C Max. R.A. (2nd neck), %	No. of Blows for C	D Max. R.A. (at parallel portion) %	No. of Blows for D	E R.A. (static), %	F Max. Elongation, %	No. of Blows for F	G Min. Elongation, %	No. of Blows for G	H Elongation (static), %
Mild Steel (normalized)	70	446	62	230	52	218	35	218	60	53·8	218	35	466	39
Mild Steel (as received)	60–62	5 to 1684	60–62	5 to 1684	27·5	56	22	56	58	22·3	56	12·9	1684	15
Brass (60/40) ...	75·8	18 to 106	71·5	7	35	7	30	7	67	42·0	7	28·8	417	35·2
Aluminium ...	94	203 to 303	8·8	8	65	303	32	303	94	66·5	303	45·7	8	36
Aluminium Alloy B.A.26	(7404) 76·2	(3·2) 89	72·5	14	33	128	31·4	32	63	45·3	32	33·1	482	30
Copper	76	193 to 774	70	4	42·5	195	37–40	193 to 195	74	69·3	195	39·7	763	50·7
Lowmoor Iron ...	70	210	64	5	24	92	6	5	66·5	23·7	5	185	210	40·0

as for static, but in this case $A = Cf(L)$; where C is a constant, and $f(L)$ is an unknown function of the gauge length. With regard to factor B, the same assumption may be made as for the static test.

$$\therefore \text{Elongation } (\%) = Cf_2(L) + \frac{K^1 d}{L}, \quad \ldots\ldots\ldots(3)$$

where $f_2(L) = f(L)/L$.

Equation (3) is only the same as (2) when $f_2(L) = 1$. This has yet to be proved, and my own experimental results would suggest otherwise.

The value of the constants K and K^1 depend upon the length (or spread) of the neck.

From Fig. B it will be seen that, although the reduction in area for impact is slightly larger than that for static tests, the spread of the final neck along the specimen for impact and static tests is practically the same. This implies that K is only slightly greater than K^1. Mr. Vivian gives $K = 2K^1$.

Equation (1) given by Mr. Vivian is the accepted form of equation for static tests, but to apply the same type of equation to impact tests seems to me incompatible with the known mode of deformation during impact, and certainly at variance with my own experimental results.

Mr. Vivian takes portion A as the true measure of the ductility of a metal. It is essential to be clear what we mean by ductility. If it is regarded as a fundamental property of the metal, then it must be measured by a quantity which is little affected by the rate and method of straining. The results of single and repeated impact tests on various metals are given in Figs. C, D, E, and F, and the more important results collected in Table I.

The diagrams show that of all the possible methods of measuring ductility, the measurement which remains most constant is the percentage reduction in area at fracture. Therefore, it seems to me that this is the best measure of the true ductility of the metal.

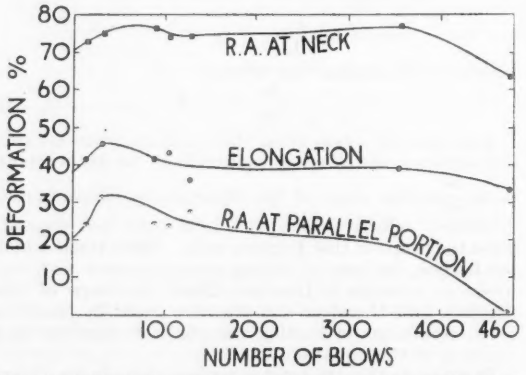


Fig. F—Effect of number of blows on the ductility of aluminium alloy B.A. 26

If, however, one wants to know the portion of this ductility which will be available under certain service conditions then one must bear in mind that the available ductility depends upon the applied stress system and the conditions of straining. From this point of view one has admiration for the determination and energy which Mr. Vivian has devoted to correlate the effective ductilities which may reasonably be anticipated under various conditions. I am glad if Fig. 28 has been of any value to him, but I am reluctant to draw positive evidence from this diagram. Equation (2), given by Mr. Vivian, must be regarded as empirical, having no fundamental significance.

B. I. S. R. A.

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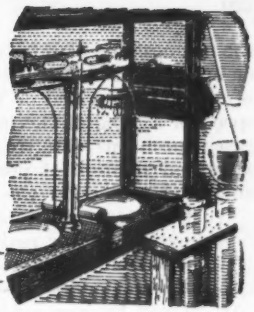

Cementiferous Paints

By J. E. O. Mayne, Ph.D., F.R.I.C., A.R.C.S., D.I.C. and R. S. Thornhill, M.A.(Cantab.), Ph.D.(Lond.), F.I.M.

SYNOPSIS

The paper describes researches designed to elucidate the mechanism of the setting on and the protection of steel by cementiferous paints. These paints are based on mixtures of zinc dust and certain chloride solutions which produce a matrix of oxychloride cement by action on the zinc ; sufficient metallic zinc is left to provide cathodic protection to steel exposed at gaps or pores in the coat. If the electrical contact between steel and zinc, and that between the zinc particles, is good, the potential of the painted steel is similar to that of zinc sheet ; thus a study of potential movements provides an assessment of protective value. Of the chlorides tested, those of barium and of strontium produce setting at high and low humidities, magnesium and calcium chlorides are satisfactory except at very high humidities.

The oxychloride matrix is unstable in the presence of water, and cementiferous paints slowly disintegrate when immersed in sea-water. It is concluded that the best results will be obtained if the cementiferous paint is covered with an organic sealing coat—a prediction confirmed by K. A. Pyefinch in a separate paper.

Introduction

Early History

THE cementiferous paints arose out of attempts initiated by U. R. Evans, in August, 1940, to obtain rapidly setting aggregates of metal and cement by mixing steel filings with magnesium chlorate. The iron reduced the magnesium chlorate to magnesium chloride and magnesia roughly in the proportions needed to produce Sorel cement. Instead of magnesium chlorate, mixtures of magnesium sulphate and potassium or barium chlorate were sometimes employed, and other substances, such as ammonium chloride, were often added to accelerate the reaction, and carborundum to improve the hardness ; in some cases sufficient steel was left after setting to confer magnetic properties on the mass.

When zinc dust was substituted for steel filings, the mixture could be brushed over a steel surface, forming a type of inorganic paint, and if the zinc content was sufficiently high the coating thus produced was capable of affording considerable protection to the metal when immersed in sea-water.

Possible Advantages of Cementiferous Paints

It was felt that such paints might prove superior to oil paints, for the following reasons :

(i) Being based on an aqueous medium, they should be suitable for application to wet metallic surfaces.

(ii) Any corrosion products on the surface of the metal would be incorporated into the body of the paint as part of the pigment.

(iii) Paints rich in zinc dust should effectively protect partially descaled surfaces, since the breaks in the scale, which are potentially anodic points, would receive cathodic protection, and the dangerous combination of large cathode and small anode would be modified, thus preventing pitting of the metal and undermining of the scale.

Preliminary Investigation

A number of paints were prepared containing ingredients added to improve brushing properties. These were applied to rusty steel specimens and tested by partial immersion in sea-water. The paints based on magnesium chlorate set too quickly to be of any use for industrial application, only a few square feet could be coated before they became too stiff.

Further development work was undertaken with the object of producing a paint which could be easily mixed before application, and when mixed would have a ' pot life ' of at least 1 hr. It was found that

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the magnesium chlorate could be replaced by barium or magnesium chloride, that iron oxide in the form of either Indian Red or Venetian Red increased the speed of setting of the mixture, and that when the rusty specimens were treated before painting with a saturated solution of potassium antimony tartrate, enhanced protection was obtained.

At the stage when the authors took over the investigation, it was realized that little was known of the reactions between zinc dust and solutions of either barium or magnesium chloride, and also the part played by iron oxide and potassium antimony tartrate during the setting of the cement. A careful investigation was therefore carried out on the setting reaction, and this was followed by an examination of the mechanism of the protective action of a number of cementiferous paints. The following paper is a short account of these investigations.

THE MECHANISM OF THE SETTING OF CEMENTIFEROUS PAINTS

The Nature of the Cement

The simplest type of cementiferous paint, E 378, had the composition :

Zinc dust	112 g.
Magnesium chloride solution (44%) ...	30 c.c.

The strength of the magnesium chloride solution is expressed as the percentage by weight of the hexahydrate. The ingredients were mixed together with a paint brush—no grinding was necessary—and the mixture had a 'pot life' of at least 1 hr. When painted on metal or glass the mixture set within ½ hr.

It is almost certain that all paints containing zinc dust and chlorides set through the development of an oxychloride cement. Some of the zinc is used up in the process, but the remainder is available for the protection of the supporting metal.

In the literature, two oxychlorides are mentioned which have cement-forming properties. These are :

(*a*) *Magnesium oxychloride or Sorel cement*—This is prepared by mixing calcined magnesia with a strong solution of magnesium chloride. According to Lukens,[1] the magnesia first dissolves in the chloride solution to an amount which is greatly in excess of the normal solubility in water (20–23 mg./litre). During this process the solution becomes supersaturated with magnesium oxychloride, and this later separates out as a gel. The workers who have studied this reaction from the phase-rule angle agree that in the oxychloride 3 mols of MgO are combined with 1 mol of $MgCl_2$, but differ in regard to the number of molecules of water held in combination.

(*b*) *Zinc oxychloride*—This is prepared in the same way by mixing zinc oxide with a strong solution of zinc chloride. Zinc oxide is a more insoluble body than magnesium oxide. Its solubility is given by Remy and Kuhlmann[2] as 2·92–3·06 mg./litre, but undoubtedly it will depend on the degree of calcination. At low concentrations of zinc chloride the formula of the oxychloride has been given as $4ZnO.ZnCl_2.6H_2O$,[3] $4ZnO.ZnCl_2.5H_2O$,[4] and $5ZnO.ZnCl_2.8H_2O$.[5] At high concentrations of zinc chloride the formulæ given are $ZnO.ZnCl_2.1\frac{1}{2}H_2O$,[3] $ZnO.ZnCl_2.H_2O$,[4] whilst Holland[5] claims the existence of two compounds of ZnO and $ZnCl_2$ containing one and two molecules of water respectively.

There is, unfortunately, no information on the manner in which the oxychlorides are formed. It is not known whether the zinc oxide dissolves and is reprecipated as an oxychloride in the manner described[1] for magnesia. On the other hand, in view of the speed with which setting occurs the reaction may be a heterogeneous one. Information on these points would have been very helpful in discussing the mechanism of setting; as it is, certain parts of the argument which follow remain problematical.

Methods of Production of Oxychloride Cements

In a simple mixture of zinc dust and magnesium chloride the necessary constituents for producing either or both of these cements are not initially present, but they can be produced in various ways :

(*a*) By the electrochemical action of air-saturated magnesium chloride solution on zinc dust, which will give magnesium hydroxide according to the general equation :

$$Zn + MgCl_2 + H_2O + O \rightarrow ZnCl_2 + Mg(OH)_2.$$

Setting could then occur through the formation of magnesium oxychloride.

(*b*) Hydroxyl ions produced at the local cathodes might react with a portion of the zinc chloride formed at the anodes, giving zinc hydroxide. This, reacting with the remainder of the zinc chloride, would yield zinc oxychloride.

(*c*) Zinc chloride produced anodically might react with the zinc oxide present as an impurity in zinc dust, to give zinc oxychloride. The commercial dust used in the experiments was found to contain from 5·7–8·3% of zinc oxide, and in many paints zinc oxide was intentionally added.

(*d*) In addition to the two oxychlorides mentioned above it is possible that mixed oxychlorides of the types $xMgO.ZnCl_2$ and $yZnO.MgCl_2$ may exist.

In order to obtain information on which of these mechanisms was operative, experiments were carried out on the rate of setting of mixture of oxides and chloride solutions.

The Reaction between Magnesium Oxide and Certain Chloride Solutions

Solutions of zinc chloride and magnesium chloride were ground in a mortar with magnesium oxide. The mixtures were painted on rusty steel, and the time of setting noted.

The results (Table I) show that magnesium oxide reacts much more rapidly with zinc chloride, forming a cement, than it does with magnesium chloride to form magnesium oxychloride.

Equal weights of magnesium oxide were next shaken with :

(i) Distilled water;
(ii) An equal volume of saturated zinc chloride solution.

Table I

TIME OF SETTING OF MAGNESIUM OXIDE AND ZINC OXIDE CEMENTS

	Magnesium Chloride Solution (30%)	Zinc Chloride Solution (Saturated)
Magnesium oxide	Not dry in 6 hr. Set within 22 hr.	Set rapidly in the mortar. Just possible to apply by brush
Zinc oxide ...	24 hr.	Very fast, not possible to apply by brush

Both solutions were then filtered and a mixture of ammonium hydroxide and sodium phosphate added. The volume of precipitate obtained from (ii) was much greater than from (i), suggesting that in a paste made from magnesium oxide and zinc chloride double decomposition occurs :

$$MgO + ZnCl_2 + H_2O \rightleftharpoons Zn(OH)_2 + MgCl_2,$$

the subsequent setting being due to the formation of zinc oxychloride, which is known to set very rapidly.

These results suggest that if mechanism (*a*) is operative, the final product should be zinc oxychloride and not magnesium oxychloride, and that mixed oxychlorides of the type xMgO/$ZnCl_2$ probably do not exist.

The Reaction between Zinc Oxide and Certain Chloride Solutions

The experiments were repeated with zinc oxide substituted for magnesium oxide.

The results (Table I) show that the system ZnO–$ZnCl_2$ sets very rapidly with the formation of zinc oxychloride ; the mixture ZnO–$MgCl_2$ solution sets much more slowly, either because a cement of this type, if it exists, has a slow setting time, or because the ingredients necessary to produce magnesium or zinc are obtained with difficulty from the combination.

The Setting of E 378

When zinc dust is mixed with magnesium chloride solution the setting is much faster than the rate of formation of magnesium oxychloride, and is presumably due to the formation of zinc oxychloride.

Table II

THE REACTION BETWEEN VARIOUS CHLORIDE SOLUTIONS AND A MIXTURE OF 98% OF ZINC DUST AND 2% OF ZINC OXIDE

Chloride Solution		Condition of Paint in Mortar
Cation	Concentration, %	
Lead ...	Saturated	Brushable after 1 hr.
Stannous ...	20	Too stiff to apply after 5 min. Set in 10 min.
Cadmium ...	20	Turned solid during mixing
Aluminium	20	Set within 3 min.
Ferric ...	20	Stiff in 10 min., too thick to apply after 15 min.
Ferrous ...	20	Gas evolved. Set in 5 min.
Manganese	20	Thickens slowly, only just brushable after 1 hr.
Chromium	20	Set in 10 min.
Nickel ...	20	Gas evolved. Set in 5 min.
Cobalt ...	20	Gas evolved. Set in 15 min.
Zinc	20	Set within 5 min.
Barium ...	20	Brushable after 1 hr.
Strontium ...	20	Brushable after 1 hr.
Calcium ...	20	Brushable after 1 hr.
Ammonium	20	Set within 10 min.
Magnesium	20	Brushable after 1 hr.
Sodium ...	Saturated	Brushable after 1 hr.
Potassium ...	Saturated	Brushable after 1 hr.

The secondary hardening of E 378, which continues after the initial setting, may be due to the system ZnO–$MgCl_2$ or MgO–$MgCl_2$. This cannot be very important, since satisfactory paints have been prepared with the chlorides of barium, strontium, and calcium, and these metals do not form oxychlorides.

The Reaction between Zinc Dust and Various Chloride Solutions

In order to obtain further information about the mechanism of setting, the reaction between zinc dust and a number of different chloride solutions has been examined. The chlorides of arsenic, antimony, bismuth, copper, mercury, silver, and tin have not been examined, since they were regarded as either too reactive or insufficiently soluble in water. The chloride solution was ground in a mortar with a mixture containing 98% of zinc dust and 2% of zinc oxide ; the condition of the paint over a period of 1 hr. is recorded in Table II.

If, as already suggested, setting is associated with the formation of zinc oxychloride, zinc chloride must first be formed in one of the following four ways :

(i) If the chloride solution used is that of a metal more noble than zinc, direct replacement may take place.

(ii) If the cation can exist in two states of oxidation, the zinc dust may reduce it from the higher to the lower state.

(iii) The chloride solution (especially if made acid by hydrolysis) may act chemically or electrochemically with the zinc dust, with rapid elimination of hydrogen.

(iv) It may act on the zinc dust with absorption of oxygen.

Table II shows that, of the 18 chlorides examined, 10 had set or could not be applied by a brush at the end of 1 hr. These 10 solutions probably reacted in accordance with mechanisms (i–iii) inclusive. It was concluded, therefore, that for the production of a paint which would have a ' pot life ' of at least 1 hr., the chloride solution must react in the manner described in (iv).

Of the chlorides examined only eight gave paints with a satisfactory ' pot life.' These eight paints were next applied to rusty steel specimens which had been wire brushed (to remove loose rust), in order to determine whether cement formation was sufficient to give a coherent dry film. The painted specimens were allowed to dry in the laboratory for 24 hr. at a relative humidity of 61%,* and the condition of the coating was noted after they had been rubbed with the finger covered with a velvet cloth. If the paint were easily removed by this treatment, the result was recorded as " bad "; if removed with difficulty, " fair "; if no paint could be removed at all, " good." The results (column 1, Table III) show that lead chloride yielded a poor paint, probably owing to the

* The relative humidity was measured by means of a wet and dry bulb thermometer placed in front of an electric fan, so that the air velocity was greater than 3 m./sec.

Table III
EFFECT OF HUMIDITY ON THE DRYING OF CEMENTIFEROUS PAINTS

Chloride Solution		Resistance of Paint to Dry Rubbing when Dried			
Cation	Concentration, %	(1) In Laboratory (Relative Humidity 61%)	(2) In Desiccator at Room Temperature (over Solid Calcium Chloride)	(3) In Desiccator at Room Temperature (over Water)	(4) In Desiccator at 4° C. (over Water)
Lead	Saturated	Paint removed	...	...	...
Barium ...	20	Good	Good	Good	Good
Strontium ...	20	Fair	Fair	Fair	Good
Calcium ...	20	Good	Good	Good	Bad
Sodium ...	Saturated	Good	Fair	Bad (Paint still wet)	...
Potassium ...	Saturated	Good	Fair	Bad (Paint still wet)	...
Manganese ...	20	Good	Good	Good	Bad (Paint still wet)
Magnesium ...	20	Good	Good	Good	Fair

low solubility of lead chloride at room temperature ; paints containing solid lead chloride set within 15 min.

THE EFFECT OF HUMIDITY ON THE SETTING REACTION

Qualitative Tests

Paints which dry satisfactorily in an atmosphere of relative humidity 61% have been made from seven chloride solutions. Since painting is frequently carried out at different temperatures and humidities, the effect of humidity and temperature on drying was next examined.

In the first series of experiments, rusty specimens (previously wire brushed) were painted and allowed to dry for 24 hr. in a desiccator over solid calcium chloride at room temperature ; they were then examined and rubbed. The results (column 2, Table III) show that all seven chloride solutions produced paints in which cement formation occurred quicker than the evaporation of moisture from the paint ; this was confirmed by drying paints in an air current, when quite satisfactory coats were obtained.

Next, painted specimens were allowed to dry in a desiccator containing water at room temperatures. The results (column 3, Table III) show that the chlorides of sodium and potassium yielded paints which would not set. Possibly the soluble alkali formed at the cathodes interfered with the formation of zinc oxychloride either by precipitating the zinc chloride as zinc hydroxide, or by absorbing water, thus indicating that only the chloride of a metal with a sparingly soluble hydroxide can yield a satisfactory paint.

In order to examine the behaviour of cementiferous paints at low temperatures in an atmosphere of relative humidity 100%, five of the paints used in the previous experiment were tested as follows. Two vessels containing pigment and chloride solution respectively, together with a desiccator containing water, were placed in a refrigerator at 4° C. for 1 hr. They were then removed, the paints rapidly mixed, and applied to specimens which were at once placed in the desiccator and returned to the refrigerator. Twenty-four hours later the condition of each specimen was that recorded (column 4, Table III). It is clear that paints can only set under these conditions if the chloride used is not hygroscopic in the solid state, and only the chlorides of barium and strontium fulfil this requirement. For lower relative humidity values, paints made with the chlorides of calcium, manganese, or magnesium are satisfactory.

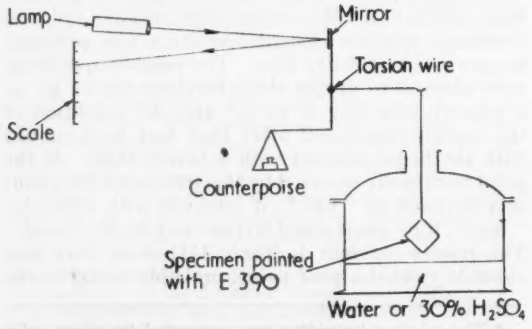

Fig. 1—Diagrammatic representation of apparatus used in following the changes of weight during drying of E 390 at two humfdities

Quantitative Tests

In addition to the qualitative tests, measurements have been made of the changes in weight when one paint, E 390 (for composition *see* Table V), dried in atmospheres of two different relative humidities. The apparatus employed (*see* Fig. 1) was part of a torsion balance used for surface-tension measurements. It consisted of a steel wire supported in a horizontal position, with an arm attached to the centre. On one end of this arm was the steel specimen which hung in a desiccator either over water or a 30% solution of sulphuric acid. A balancing weight and mirror was attached to the other end of the arm. Changes of weight could be followed by movements of a spot of light. Calibration was not good, since the wire was overstrained, but a shift of 1 cm. was roughly equivalent to a change in weight of 0·05 g.

Table IV

THE EVOLUTION OF GAS FROM CEMENTIFEROUS PAINTS

Constituent	Amount Mixed	Change in Volume after Standing, c.c.						
		0 hr.	16 hr.	19 hr	22 hr.	24 hr.	40 hr.	48 hr.
Zinc dust ... ... $MgCl_2.6H_2O$ (44% Solution)	14 g. 2·5 c.c.	0	−0·5	−1·1	−1·0	−0·5	−2·7	−0·7
Zinc dust ... ... Indian Red ... ... $MgCl_2.6H_2O$ (44% Solution)	11·3 g. 0·6 g. 2·5 c.c.	0	33·0	39·3	51·0	60·2	Discontinued	

The results obtained are shown in the form of a graph in Fig. 2, in which the changes in weight of the specimen have been plotted against time. It can be seen that when placed over 30% sulphuric acid, setting occurred accompanied by loss in weight ; on the other hand, when placed over water there was an increase in weight but no setting, although the specimens set quite normally when taken out of the desiccator and subsequently exposed to the air.

ACCELERATION OF THE RATE OF SETTING

Iron Oxide

Earlier in this investigation it was found that ferric oxide accelerated the rate of setting of mixtures of zinc dust and magnesium chloride solution ; such mixtures evolved gas when allowed to set in the mortar, and a spongy cement was formed.

To measure the volume of gas evolved, mixtures were placed in a sealed tube connected with an Ostwald gas-measuring burette. Results obtained at room temperatures over a period of 2 days are shown in Table IV.

The evolution of gas was probably due to the fact that ferric oxide was a sufficiently good electronic conductor for the cell :

$$Fe_2O_3/MgCl_2 \text{ soln.}/Zn$$

to function with the rapid formation of zinc chloride and the reduction of ferric oxide to metallic iron or magnetite, both of which are conductors ; the iron/zinc (or magnetite/zinc) couple then produced hydrogen. As shown later, the ability of cementiferous paints to reduce iron oxide or rust to metallic iron or magnetite is important in connection with the protection of rusty surfaces.

Red Lead

The explanation suggested receives support from the fact that the mixture red-lead/zinc-dust/magnesium-chloride-solution sets almost instantaneously with the evolution of heat. Red lead is known to be a good electronic conductor, and is also an oxidizing agent ; the particles of pigment in contact with zinc dust can thus act as very effective cathodes.

Lead and Graphite

The setting reaction is also stimulated by graphite and metallic lead powder ; both materials are good electronic conductors, and both are cathodic to zinc.

THE MECHANISM OF THE PROTECTIVE ACTION OF CEMENTIFEROUS PAINTS

Preliminary Investigations

The paints developed during the preliminary investigation were tested by partial immersion in sea-water. In these tests steel specimens roughly 3 × 1 in. were painted, dried, and partially immersed in about 60 c.c. of natural sea-water contained in beakers. The beakers were stored on shelves at room temperature, and from time to time the evaporation was made up by the addition of distilled water. The surface condition of the metal prior to painting was varied, and in some experiments the paint film was broken by a vertical scratch-line which exposed the bare metal. These tests indicated that the most promising paints contained either a relatively high proportion of zinc dust or a certain amount of arsenious oxide. This conclusion was confirmed by raft immersion tests in the sea ; these tests were kindly carried out by Dr. J. C. Hudson at Caernarvon, and Professor J. E. Harris at Millport.

THE MECHANISM OF THE PROTECTIVE ACTION OF PAINTS RICHLY PIGMENTED WITH ZINC DUST

It has already been shown[6] that paints prepared from organic vehicles heavily pigmented with zinc dust are capable of affording cathodic protection to steel. Experiments have been performed in order to find out whether the zinc dust used in cementiferous

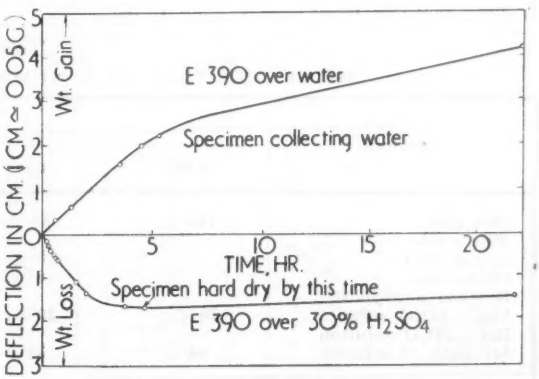

Fig. 2—Setting of E 390 at two different humidities

paints was acting in a similar way ; at the same time the effect of the following factors was examined :

(*a*) The addition of small quantities of various pigments.

(*b*) The surface condition of the steel.

(*c*) The concentration of the chloride solution.

(*d*) The composition of the chloride solution.

In order that zinc may confer cathodic protection on iron, the zinc must be in metallic contact with the iron, and the electric circuit between the two metals must be completed by an electrolytic conductor. Between the two metals there are two resistances, R the electronic or metallic resistance, and r the electrolytic resistance. When zinc dust is used in a paint the value of R may or may not be appreciable according to the composition of the paint ; but the value of r depends on the size of the pores in the paint film, and on the conductivity of the liquid within them ; it is, therefore, a function of the service conditions. Evans[7] has shown that when R is small compared with r, in the absence of polarization, the coated specimen will take up a potential approaching that of a piece of zinc, and that as R increases or r decreases the potential will have an intermediate value until, when R is large compared with r, the potential will be that of a piece of iron.

Measurement of the potential of coated-steel specimens partially immersed in sea-water, forms a simple method of estimating the degree of contact between the zinc particles, since the potential will be similar to that of zinc when the metallic resistance R is low. Potential measurements also yield information with respect to the useful life of the zinc dust : thus as the zinc is consumed the potential will rise, since R will be increased by the loss of metallic contact ; the blockage of the pores by the corrosion product will tend to increase r, but not at the same rate. Throughout the following investigation, therefore, the changes in potential of coated specimens have been examined, and these have been correlated with the appearance of the specimens and signs of any breakdown of the paint.

The Effect of the Addition of Small Quantities of various Pigments and of the Surface Conditions of the Steel

The composition of a number of cementiferous paints developed in the preliminary investigation is given in Table V.

In the first series of tests mild steel specimens, possessing four different kinds of surface, were coated with three different cementiferous paints, partially immersed in sea-water, and the potential measured over a period of time against a saturated calomel electrode by means of a Cambridge valve potentiometer. Four uncoated steel specimens and one specimen of zinc were included in the experiment.

The surface condition of the specimens before painting was as follows :

Code Letter	Surface Condition
" B "	Specimens of hot-rolled mild steel (*see* Appendix for composition) were weathered on the laboratory roof at Cambridge for about a year. At the end of this period all the mill scale had disappeared. The specimens were removed from the roof just before painting and the loose rust removed with a mechanical wire brush.
" B + TE "	These were " B " specimens which had received a wash of a saturated solution of potassium antimony tartrate ½ hr. before the application of the cementiferous paint.
" P "	These specimens were cut from annealed mild-steel sheet (*see* Appendix for composition) similar to that used in the manufacture of tinplate. The specimens were pickled in dilute hydrochloric acid containing a pickling inhibitor, washed under the tap, dried on filter paper, and stored in a desiccator until required.
" M "	These were cut from the middle of an annealed mild-steel sheet, where there was no visible film of scale, although annealing scale existed at the edges.

The vessels containing the specimens were placed on a shelf at room temperature, and from time to time the evaporation was made up for by the addition of distilled water. The experiments lasted 448 days (approximately 15 months). All the specimens were then covered with rusty nodules, and in nearly every case loose rust had appeared in the sea-water ; the " P " and " M " specimens were in a better condition than the " B." It should be noted that these paints did not behave quite as well as the zinc-rich organic paints, which under similar conditions showed no signs of rust after 20 months' partial immersion.[6] From the potential measurements, given in Table VI, it can be seen that the treatment of the rusty specimens with a solution of potassium antimony tartrate

Table V

THE COMPOSITION OF A NUMBER OF CEMENTIFEROUS PAINTS

Constituent	Code No. of Paint				
	E 378	E 390	E 581	E 412	E 552 A
Zinc dust	112 g.	56 g.	507 g.	336 g.	168 g.
Zinc oxide	...	...	8·6 g.	6 g.	6 g.
Indian Red	...	6 g.	...	...	6 g.
China clay	...	6 g.	...	6 g.	...
Barium phosphate ...	...	...	...	7 g.	...
$MgCl_2.6H_2O$ solution ...	20 c.c.	20 c.c.	...	70 cc.	30 c.c.
$BaCl_2.2H_2O$ solution ...	...	...	91 c.c.	...	...
Strength of solution ...	44%	31%	27% (sat.)	22%	44%

Table VI

POTENTIALS OF STEEL SPECIMENS COATED WITH CEMENTIFEROUS PAINTS PARTIALLY IMMERSED IN SEA-WATER

Reference Electrode Calomel/Saturated-Potassium-Chloride

Paint	Surface	Potential after Immersion, V.										
		1 hr.	1 day	2 days	3 days	5 days	7 days	21 days	28 days	33 days	63 days	448 days
E 378	" B "	−0·467	−0·569	−0·584	−0·587	−0·588	−0·589	−0·607	−0·634	−0·635	−0·634	−0·635
	" B+TE "	−0·428	−0·588	−0·666	−0·688	−0·720	−0·741	−0·834	−0·883	−0·909	−0·856	−0·642
	" P "	−0·760	−0·705	−0·674	−0·666	−0·662	−0·649	−0·642	−0·658	−0·670	−0·662	−0·624
	" M "	−0·751	−0·742	−0·681	−0·678	−0·665	−0·670	−0·664	−0·674	−0·694	−0·676	−0·618
E 412	" B "	−0·778	−1·027	−0·997	−0·980	−0·988	−0·987	−0·938	−0·904	−0·819	−0·608	−0·670
	" B+TE "	−0·642	−1·029	−1·022	−0·976	−0·977	−0·976	−0·965	−0·996	−0·983	−0·820	−0·650
	" P "	−1·063	−0·994	−0·789	−0·676	−0·673	−0·615	−0·629	−0·634	−0·650	−0·600	−0·655
	" M "	−1·061	−1·010	−0·924	−0·860	−0·809	−0·756	−0·646	−0·657	−0·668	−0·600	−0·646
E 552 A	" B "	−0·444	−0·650	−0·575	−0·584	−0·586	−0·558	−0·601	−0·622	−0·631	−0·632	−0·632
	" B+TE "	−0·400	−0·647	−0·628	−0·646	−0·665	−0·676	−0·691	−0·720	−0·717	−0·800	−0·636
	" P "	−0·930	−0·821	−0·754	−0·740	−0·770	−0·725	−0·650	−0·658	−0·683	−0·677	−0·654
	" M "	−0·847	−0·811	−0·781	−0·773	−0·773	−0·750	−0·708	−0·671	−0·725	−0·652	−0·603
None	" B "	−0·440	−0·541	−0·553	−0·561	−0·570	−0·589	−0·613	−0·626	−0·642	−0·612	−0·600
	" B+TE "	−0·405	−0·513	−0·535	−0·548	−0·565	−0·581	−0·589	−0·616	−0·623	−0·600	−0·679
	" P "	−0·608	−0·696	−0·698	−0·691	−0·690	−0·694	−0·664	−0·682	−0·676	−0·647	−0·671
	" M "	−0·594	−0·696	−0·696	−0·694	−0·692	−0·695	−0·672	−0·687	−0·683	−0·650	−0·671
None	Zinc	−1·052	−1·059	−1·054	−1·043	−1·048	−1·018	−1·015	−1·028	−1·041	−0·975	−1·054

before painting decreased the value of R/r, thereby increasing the effective life of the zinc dust. Furthermore, E 412 was the only paint in which the zinc particles were in good contact with the steel; this occurred with all four surfaces. In the case of the rusty specimen coated with E 412 the contact was poor 1 hr. after immersion, but it improved on standing. This improvement was probably associated with the slow reduction of the rust to iron or magnetite, thus bringing the paint into better electronic contact with the steel, an effect observed with organic paints highly pigmented with zinc dust.[6]

In the paints examined, the concentration of the magnesium chloride solution was not constant. The effect of this variable on the protection was next examined.

The Concentration of the Magnesium Chloride Solution

This experiment was performed under more severe conditions than the previous one. The paint coat was broken by a scratch-mark before the specimens were partially immersed in the sea-water. Rusty specimens were used, and since it has been shown that the minimum potential was reached within 3 days, the experiments lasted only 5 days. The pigment mixtures used were those normally employed in the paints E 378, E 412, and E 390, and have been called D.P. (Dry Powder) 378, D.P. 412, and D.P. 390. The pigments were ground in a mortar with solutions of magnesium chloride of different strengths. The results obtained are shown in Table VII.

The specimens were of annealed mild-steel sheet (*see* Appendix for composition) which had been weathered on the roof for some months. The specimens were removed from the roof and the loose rust removed with a mechanical wire brush just before they were painted.

The specimens showing a potential more negative than about − 0·780 V. developed no rust at the

Table VII

EFFECT OF THE CONCENTRATION OF MAGNESIUM CHLORIDE SOLUTION ON THE PROTECTIVE ACTION OF CEMENTIFEROUS PAINTS

The strength of the chloride solution is expressed as a percentage (by weight) of $MgCl_2.6H_2O$.

Pigment*	Concentration of Magnesium Chloride Solution, %	Potential after Immersion, V.				
		1 hr.	1 day	2 days	3 days	4 days
D.P. 378	44	−0·633	−0·678	−0·690	−0·710	−0·698†
	33	−0·658	−0·702	−0·712	−0·743	−0·712†
	22	−0·606	−0·655	−0·682	−0·699	−0·780
D.P. 412	44	−0·681	−0·727	−0·734	−0·747	−0·845
	33	−0·723	−0·736	−0·753	−0·782	−0·873
	22	−1·008	−1·035	−1·038	−1·029	−1·022
D.P. 390	44	−0·582	−0·637	−0·652	−0·659	−0·667†
	33	−0·583	−0·654	−0·677	−0·679	−0·680†
	22	−0·566	−0·608	−0·618	−0·617	−0·627†

* The composition of D.P. (Dry Powder) 378, D.P. 412, and D.P. 390 are given in Table V.
† Denotes corrosion at the scratch-line.

scratch-line, thus suggesting that a measurement of potential affords guidance with regard to the protective value of the coat. It would seem that the zinc was protecting the steel cathodically.

It was concluded that :

(1) D.P. 412 was better than D.P. 378, which was in turn better than D.P. 390.

(2) A 22% solution of $MgCl_2.6H_2O$ was the best of the magnesium chloride solutions.

Chlorides other than Magnesium Chloride

In a previous section of this paper it has been shown that satisfactory cementiferous paints can be made from the chlorides of magnesium, calcium, strontium, barium, and manganese. Paints have been prepared from solutions of these chlorides together with D.P. 412 and D.P. 378. Paint D.P. 390 was not used owing to the unsatisfactory results obtained in the experiments described above. The experimental procedure was unchanged.

The results obtained, shown in Table VIII, indicated that the chlorides of barium, strontium, and calcium yield paints in which the zinc dust is in good contact with the steel, and that the optimum concentration of each chloride solution is roughly that equivalent to a 22% solution of $MgCl_2.6H_2O$. Manganese chloride solution did not form satisfactory paints : when the concentration exceeded 12%, breakdown at the scratch took place ; this may have been due to the formation of manganese dioxide which could act as an alternative cathode, thereby diminishing the protection of the steel and accelerating the rate of setting.

In regard to the two pigment mixtures D.P. 412 and D.P. 378, the former was found to be the better when used in conjunction with magnesium chloride. A similar result was obtained with barium chloride solution, but the effect was not so great. Further experiments indicated that this was not due to the presence of zinc oxide in D.P. 412, and it is doubtful whether it could be attributed to the china clay ; it was probably associated with the presence of barium phosphate. It is probable that the barium phosphate was either improving the electronic contact between the zinc dust and the steel, or increasing the electrolytic resistance in the pores of the paint, but no further conclusion can be drawn until more work has been done. It is along these lines, however, that improvements in the paints might be made.

Calcium chloride and strontium chloride solutions gave better results with D.P. 378 than with D.P. 412, but the difference was not very great.

The Action of a Solution of Potassium Antimony Tartrate

It has already been shown, in Table VI, that the treatment of a rusty specimen with a solution of potassium antimony tartrate before painting, decreased the ratio of the electronic to the electrolytic resistance. A decrease in the electronic resistance could be brought about in two ways :

(i) By the formation of metallic bridges through the rust, thus improving the contact between the zinc and the steel.

(ii) By increasing the contact between the zinc particles, thereby making a greater fraction of the zinc perform a useful function.

In order to decide which was operative, pickled specimens washed with potassium antimony tartrate

Table VIII

THE EFFECT OF A NUMBER OF CHLORIDE SOLUTIONS ON THE PROTECTIVE ACTION OF CEMENTIFEROUS PAINTS

The strength of the chloride solution is expressed as the percentage (by weight) of $CaCl_2$, $SrCl_2.6H_2O$, $BaCl_2.2H_2O$, and $MnCl_2.4H_2O$. Specimens were similar to those used in the previous experiment.

Pigment	Chloride Solution	Concentration, %	Potential after Immersion, V.				
			1 hr.	1 day	2 days	4 days	5 days
D.P. 412	Calcium	12	−0·962	−1·011	−0·976	−0·990	−0·986
	Calcium	25	−0·750	−0·871	−1·003	−0·998	−0·987
D.P. 378	Calcium	12	−1·023	−1·032	−1·011	−1·012	−1·010
	Calcium	25	−0·895	−1·024	−1·005	−1·008	−1·004
D.P. 412	Strontium	20	−0·937	−0·980	−0·977	−0·988	−0·981
	Strontium	30	−0·880	−1·000	−0·973	−0·989	−0·977
	Strontium	40	−1·008	−1·010	−0·998	−1·001	−0·996
D.P. 378	Strontium	20	−0·848	−1·026	−0·989	−0·998	−0·992
	Strontium	30	−0·968	−1·027	−0·997	−1·023	−1·025
	Strontium	40	−1·026	−1·012	−1·002	−1·017	−1·023
D.P. 412	Barium	10	−1·052	−1·047	−1·049	−1·040	−1·010
	Barium	20	−1·043	−1·040	−1·038	−1·029	−1·027
	Barium	27	−1·046	−1·034	−1·040	−1·031	−1·034
D.P. 378	Barium	10	−0·786	−0·798	−0·814	−0·816	−0·918
	Barium	20	−0·846	−1·040	−1·036	−1·020	−0·940
	Barium	27	−1·027	−1·037	−1·041	−1·021	−0·952
D.P. 412	Manganese	12	−0·775	−0·821	−1·012	−0·968	−0·967
	Manganese	24	−0·560	−0·574	−0·574	−0·580	−0·575*
	Manganese	36	−0·510	−0·554	−0·553	−0·578	−0·577*
D.P. 378	Manganese	12	−0·782	−0·760	−0·747	−0·692	−0·646
	Manganese	24	−0·512	−0·550	−0·563	−0·582	−0·579*
	Manganese	36	−0·501	−0·545	−0·557	−0·600	−0·574*

* Denotes corrosion at the scratch-line.

solution, and similar unwashed specimens, were coated (in duplicate) with three different paints, partially immersed in sea-water, and their potentials measured over a period of 14 days. Pickled specimens were used since there could then be no question of bridging rust. The results obtained, given in Table IX, indicate that the relation of R to r is altered in the absence of rust, thus suggesting that the effect of the potassium antimony tartrate solution was to improve the contact between the zinc particles possibly by coating them with metallic antimony. It is possible, however, that it increases the value of r, by making the paint less porous, but it is clear that the effect does not depend on the presence of rust.

The Mechanism of Protection

The potentials in sea-water of steel specimens coated with certain cementiferous paints were, for a short time after immersion, of the same order as those of pieces of zinc, and the steel was protected where the coating had been broken with a scratch-line. Thus the zinc dust in the paint was affording the steel cathodic protection. When immersion was prolonged the potential slowly rose to a constant value which was that of iron. This increase in potential was probably due to the corrosion of the zinc particles, which increased the electronic resistance in the circuit. The alternative possibility is that it was due to a decrease in the electrolytic resistance in the pores of the paint, but this was improbable, since corrosion should have the reverse effect in that it replaces sea-water by zinc hydroxide. When the paint film on a specimen—the potential of which had attained a constant value—was broken by a scratch, corrosion rapidly occurred at the break in the paint film, thus indicating that any protection existing at that time was due to the sea-water being excluded from contact with the steel.

It was concluded that cementiferous paints rich in zinc dust protect steel in the early stages by rendering it cathodic, and consequently the hydroxides or carbonates of zinc, calcium, or magnesium are deposited on the steel. Later the zinc becomes exhausted but protection still continues, since the hydroxide or carbonate film functions as a cathodic inhibitor.

THE MECHANISM OF THE PROTECTIVE ACTION OF PAINTS CONTAINING ARSENIOUS OXIDE

One of the most successful of the early cementiferous paints, E 140, contained arsenious oxide. This was a two-component paint and had the following composition :

1st Component

Zinc Dust	84 g.
Lead Chromate	8 g.
Potassium Chromate	½ g.
Water	10 g.

2nd Component

Iron Oxide	6 g.
Arsenious Oxide	13 g.
Lead Chloride	9 g.
Water	15 g.

The two components had to be mixed by a brush on the surface of the steel before setting could take place.

Rusty specimens coated with E 140 and partially immersed in sea-water were protected at a scratch-line which exposed the bare metal, even though the potential of the specimen was always similar to that of the uncoated steel. Protection could not, therefore, have been due to the zinc. Elimination experiments indicated that it was associated with the arsenious oxide.

Further experiments in which coated mild-steel specimens 3 × 1 in. in dimensions were each partially immersed in about 60 c.c. of sea-water, showed that :

(*a*) A pickled specimen coated only on one side with E 140 did not corrode when partially immersed in sea-water.

(*b*) An unpainted pickled specimen did not corrode when placed in sea-water which already contained a specimen coated with E 140, but out of contact with it.

(*c*) Sea-water which had been in contact with E 140 did not corrode an unpainted pickled steel specimen.

Table IX

THE EFFECT OF TREATING PICKLED SPECIMENS WITH A WASH OF TARTAR EMETIC SOLUTION

The specimens were of pickled annealed mild-steel sheet.

Whether Washed in Tartar Emetic Solution	Paint	Potential after Immersion, V.				
		0 days	1 day	2 days	7 days	14 days
Yes	E 412	−1·085	−1·112	−1·105	−1·116	−1·036
Yes	E 412	−1·090	−1·112	−1·108	−1·120	−1·033
No	E 412	−1·082	−1·060	−1·042	−1·012	−0·814
No	E 412	−1·083	−1·081	−1·069	−1·066	−1·021
Yes	E 378	−1·094	−1·090	−1·058	−1·070	−1·002
Yes	E 378	−1·097	−1·104	−1·050	−1·044	−1·019
No	E 378	−1·073	−1·013	−0·916	−0·842	−0·812
No	E 378	−1·072	−1·037	−0·931	−0·864	−0·817
Yes	E 552A	−1·080	−1·044	−1·028	−0·990	−0·976
Yes	E 552A	−1·080	−1·048	−1·034	−0·994	−0·974
No	E 552A	−1·018	−0·832	−0·816	−0·784	−0·792
No	E 552A	−1·068	−1·038	−1·032	−1·011	−1·000

The sea-water used in experiment (*c*) was found to contain large quantities of arsenic when tested by the Gutzeit method as modified by Sanger and Black.[8] Arsenic was also detected, by the electrolytic method of Hefti,[9] on the surface of the pickled steel specimen after it had been carefully washed with distilled water.

These experiments suggested that the arsenious oxide was extracted by the sea-water and was then adsorbed on the surface of the steel, thereby preventing corrosion ; the mechanism of the protective action of arsenious oxide will be, however, the subject of a separate paper.

Unfortunately, all the cementiferous paints so far developed contain zinc dust ; and since the system zinc-dust/arsenious-oxide/water evolves arsine, cementiferous paints containing arsenious oxide are unsuitable for practical use.

THE BREAKDOWN OF CEMENTIFEROUS PAINTS

Bury and Davies,[10] in their paper on magnesium oxychloride cements, emphasize the fact that the solid phase or network of oxychloride needles is in equilibrium with the entrapped liquid, a solution of magnesium chloride of concentration 10·9%. If an opportunity is presented for the magnesium chloride to pick up water, the oxychloride will decompose and will revert to its original constituents. Normally this does not occur, because CO_2 forms a protective envelope of basic magnesium carbonate around the oxychloride needles, but if the CO_2 is eliminated, decomposition is rapid. Bender,[11] has similarly noted that all the chloride may be removed from oxychloride cement by boiling with water. The same may be true, broadly speaking, of zinc oxychloride, and consequently in the presence of anything but the equilibrium concentration of zinc chloride, it is to be expected that the cement binding of a cementiferous paint would undergo a gradual decomposition.

On the above theoretical grounds there are reasons for believing that cementiferous paints have only a limited life. This view is supported by the following observations :

(i) In the raft immersion tests kindly carried out by Professor J. E. Harris at Millport, single coats of cementiferous paint always showed signs of breakdown after nine months.

(ii) Glass slides coated with :

(*a*) a mixture of zinc oxide and magnesium chloride,

(*b*) E 412,

(*c*) D.P. 412 mixed with barium chloride solution,

showed thinning of the film after one month's immersion in distilled water which had frequently been changed. In this case there can be no question of the paint decomposing sacrificially.

THE USES OF CEMENTIFEROUS PAINTS

Cementiferous paints suffer from the disadvantage that they slowly break down in the presence of water, owing to the nature of zinc oxychloride ; future work, therefore, on cementiferous paints should be directed towards the evolution of a more water-resistant cement. In their present form, however, they can be very effectively sealed by a coat of the normal type of paint, hence their most promising application is as priming coats. Exposure tests have shown that they are unsuitable primers under atmospheric conditions, but under marine conditions very promising results have been obtained. This application of cementiferous paints is discussed by Mr. Pyefinch in a separate paper.

Since cementiferous paints are composed of inorganic materials they are not inflammable ; this makes them very suitable for painting the interior of ships, where the fire risk is an important factor. They are also unaffected by petrol and oils, and thus provide a possible solution to the problem of protecting the interior of oil tankers. They give considerable protection against corrosion fatigue[12] and during the war one of the paints was successfully used in the works of the Alkali Division of the Imperial Chemical Industries, Ltd., for this purpose.

Acknowledgments

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APPENDIX

The analyses of the materials used in this research are given below :

Element	Hot-Rolled Mild Steel	Annealed Mild Steel
Carbon, %	0·130	0·130
Silicon, %	Trace	0·010
Sulphur, %	0·030	0·061
Phosphorus, % ...	0·017	0·060
Manganese, %	0·390	0·350

References

1. H. S. LUKENS : *Journal of the American Chemical Society*, 1932, vol. 54, p. 2372.
2. H. REMY and A. KUHLMANN : *Zeitschrift für analytisch Chemie*, 1924, vol. 65, pp. 1, 161.
3. M. DRIOT : *Comptes Rendus*, 1910, vol. 150, p. 1426.
4. E. HAYEK : *Zeitschrift für anorganische und allgemeine Chemie*, 1932, vol. 207, p. 41.
5. H. C. HOLLAND : *Journal of the Chemical Society*, 1930, p. 643.
6. J. E. O. MAYNE and U. R. EVANS : *Chemistry and Industry*, vol. 63, 1944, p. 109.
7. U. R. EVANS : *Journal of the Birmingham Metallurgical Society*, 1944, vol. 24, p. 242.
8. F. P. TREADWELL and W. T. HALL : *Analytical Chemistry*, 1942, vol. 2, p. 84.
9. F. P. TREADWELL and W. T. HALL : *Analytical Chemistry*, 1942, vol. 2, p. 86.
10. C. R. BURY and E. R. H. DAVIES : *Journal of the Chemical Society*, 1932, p. 2008.
11. C. BENDER : *Berichte*, 1870, vol. 3, p. 932.
12. A. U. HUDDLE and U. R. EVANS : *Journal of The Iron and Steel Institute*, 1944, vol. 149, p. 109P.

Marine Exposures of Cementiferous Painting Schemes

By K. A. Pyefinch, M.A.

SYNOPSIS

The paper describes tests on painted steel specimens which were attached to rafts at Millport, and subjected to total and partial immersion in the sea for periods of up to two years.

Three schemes based on cementiferous paints have been studied.

(1) Schemes in which both the priming and the anti-fouling coats were cementiferous compositions and were not satisfactory, owing to the gradual disintegration of the cementiferous matrix.

(2) Schemes in which a cementiferous primer was sealed (to retard disintegration) with an oleoresinous anti-fouling coat, were effective only for a limited period.

(3) Schemes in which a cementiferous primer carried an oleoresinous sealing coat, which in turn was covered by an oleoresinous anti-fouling coat, gave excellent results ; they were particularly promising for use at the water-line, where the conventional combinations give unsatisfactory results.

THIS paper briefly summarizes the results of a series of cementiferous painting schemes which have been made at Millport, principally during the period 1944–1946. The data presented are purely observational, but as these results provide a record of the performance of cementiferous painting schemes under raft-exposure conditions, they are presented as a supplement to the experimental details given by Mayne and Thornhill[1] in the previous paper in this *Journal*.

Exposures of cementiferous painting schemes have been made at Millport for a period considerably longer than that which is chiefly covered by the exposures described in this paper ; the anti-fouling aspects of these earlier exposures have already been discussed in a previous publication.[2]

In all the exposures described in this paper, the application of the cementiferous priming coat was preceded by a wash of a saturated aqueous solution of potassium antimony tartrate. This was applied 15–20 min. before application of the cementiferous coat began.

EXPOSURES OF COMPLETE CEMENTIFEROUS SCHEMES

The incorporation of organic compounds into cementiferous compositions and the performance of such coatings in preventing fouling settlement has been described previously.[2] For descriptive purposes such a painting scheme, consisting of a priming coat of a cementiferous composition followed by a cementiferous anti-fouling coat, will be termed a ' complete ' cementiferous scheme, as opposed to painting schemes (described later in this paper) in which the cementiferous composition forms the priming coat only.

In the earlier series of exposures previously described,[2] a considerable number of organic substances were tested as anti-fouling agents. Only three of these, however, proved to possess effective anti-fouling properties for an appreciable period when incorporated into cementiferous compositions, and in these later exposures of such anti-fouling coatings only one of these organic compounds, phenyl mercury acetate, has been used.

The incorporation of phenyl mercury acetate into a cementiferous composition produces a coating which has appreciable anti-fouling properties. Table I summarizes the exposure records of a series of such compositions which were prepared by progressively substituting part of the iron oxide in composition E 390 by phenyl mercury acetate.

These results indicate that these coatings can give

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Table I

ANTI-FOULING PERFORMANCE OF CEMENTIFEROUS COMPOSITIONS CONTAINING PHENYL MERCURY ACETATE

Paint[a]	P/V for Anti-Fouling Coat[b]	Approx. PMA Content of Wet Paint (by wt.), %	Wet Wt. of Anti-Fouling Coat, g./sq. ft.	Approx. Toxic Content/Unit Area, g. of PMA/sq. ft.	Estimated Anti-Fouling Life, days[c]
E 390 PMA/1	100/30	4·0	26·0	1·0	175
E 390 PMA/2	100/30	6·0	24·8	1·5	190
E 390 PMA/3	100/30	7·5	21·6	1·6	190
E 390 PMA/4	100/30	11·5	26·7	3·0	>240

a. A cementiferous composition containing phenyl mercury acetate as the anti-fouling agent is designated by the addition of ' PMA ' to the number of the composition.
b. P/V indicates pigment/vehicle ratio; expressed in grammes of dry pigment and millilitres of vehicle. The 22% $MgCl_2$ solution was employed as the vehicle for these compositions.
c. The length of anti-fouling life was estimated following the scheme described in a previous paper (Pyefinch[2]).

Table II

PROTECTIVE PERFORMANCE OF A COMPLETE CEMENTIFEROUS PAINT SCHEME (1 COAT OF E 412; 1 COAT OF E 412 PMA)

Condition	Average Estimate after Exposure, % of area coated															
	17 days	35 days	63 days	94 days	119 days	157 days	185 days	212 days	240 days	274 days	303 days	335 days	366 days	391 days	425 days	447 days
Blistering ...	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	1·4	2·2	1·3	1·8	2·6	1·5(?)	?	?
Flaking ...	0	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr(?)	Tr
Rusting ...	0	0	Tr	Tr	0	Tr	Tr	Tr	0	Tr	Tr	Tr	Tr	1·0	Tr(?)	1·7
Paint Wear	0	0	0	0	0	0	0	0	0	0	0	0	0[a]	7·3	6·4	9·2

Tr indicates trace (less than 1% of area affected).
a. Some wear was apparent at this stage, but no estimate of the percentage area affected was made as the effect was then only slight.

protection against fouling settlement for periods of six months and longer and, further, that the length of anti-fouling life is roughly proportional to the toxic content of the wet paint film.

This particular set of results presents perhaps too clear a picture of the relationship between length of anti-fouling life and toxic content, as other exposures of comparable schemes give far more irregular and unpredictable results. In fact, the anti-fouling performance of many PMA coatings is such as to suggest that absence of settlement is due to factors other than the toxicity of the exposed surface. The physical condition of the surface of a cementiferous anti-fouling composition seems likely to be of importance in this respect.

Lack of reliability of anti-fouling performance is a serious disadvantage, and to this adverse characteristic another must be added. Prolonged exposure of complete cementiferous schemes in the sea indicates that, in their later stages, serious ' wear ' of the coatings occurs. The surface of the film becomes soft and friable and is gradually washed away. When this occurs anti-fouling properties, of course, disappear, and the ' worn ' surface becomes colonized by a variety of organisms, the nature of which indicates that the surface is virtually non-toxic.

This ' wear ' of a complete cementiferous scheme after a period of exposure does not, at least for a time, result in marked deterioration of the general protective properties of the schemes ; a clear indication of the protective efficacy of the thin film which presumably must remain on the steel surface.

Table II, which gives the detailed records of an exposure of a complete cementiferous paint scheme, illustrates these points and also gives some idea of the protective performance of such coatings. The paint scheme employed was one coat of the cementiferous composition E 412 as primer, followed by one coat of E 412 PMA as the anti-fouling coat. The priming coat was applied over a scaled steel surface.

An examination of Mayne and Thornhill's results[1] suggests a reason for this failure of complete cementiferous schemes. Such a scheme, to exert an effective anti-fouling effect, must remain unsealed and open to penetration by sea-water. According to Mayne and Thornhill[1] this is bound to lead to a breakdown of the cementing basis of the paint and thus to a deterioration of its substance. This is clearly borne out by the results of these exposures.

EXPOSURES OF PAINT SCHEMES BASED ON CEMENTIFEROUS PRIMERS

The difficulties encountered in exposures of complete cementiferous schemes can be minimized if the surface of this coating can be sealed so as to eliminate contact with sea-water. This sealing can be accomplished by the application of one or more coats of an oleoresinous composition—either by the direct application of an oleoresinous anti-fouling composition or by the application of an oleoresinous protective composition followed by an oleoresinous anti-fouling composition. As oleoresinous compositions in general ' key ' well to cementiferous undercoats both these possibilities are capable of practical application. It

Table III

PROTECTIVE PERFORMANCE OF A CEMENTIFEROUS/OLEORESINOUS ANTI-FOULING SCHEME (E 412: AF 337 M)

Condition	Average Estimate after Exposure, % of area coated												
	14 days	29 days	57 days	91 days	121 days	145 days	183 days	209 days	248 days	274 days	303 days	334 days	372 days
Blistering	0	0	0	2·5	3·0	2·5	4·0	1·5(?)	Tr(?)	2·0(?)	Tr(?)	Tr(?)	2·5(?)
Flaking	0	0	0	0	0	Tr	*Tr*	Tr	*Tr*	*Tr*	*Tr*	2·0	Tr(?)
Rusting	0	0	0	0	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr

Tr indicates trace (*see* notes below Table II).
In the flaking estimates, an estimate in italics indicates that at least part of the flaking recorded involved both coats, primer and anti-fouling coat.

Table IV

PROTECTIVE PERFORMANCE OF A CEMENTIFEROUS/OLEORESINOUS ANTI-FOULING SCHEME (E 412; PROPRIETARY AF) OVER LONG PERIODS OF EXPOSURE

Mean Rusting Estimate, % of area coated				
8 months	12 months	18 months	21 months	24 months
Tr	Tr	<5·0	6·0	57·5

is convenient to consider them separately, and the performance of schemes composed of a cementiferous priming coat and an oleoresinous anti-fouling coat will be described first. Exposures of all these schemes have been made both at the water-line and when fully immersed.

Exposures of Schemes of the Type Cementiferous/Oleoresinous Anti-Fouling Coat

The performance over the early stages of an example of a paint scheme of this type is summarized in Table III. The cementiferous primer was the same as that used in the previous records quoted in detail, *i.e.*, E 412, and this was painted with a single coat of the experimental anti-fouling composition 337 M, which contains cuprous and mercuric oxides as anti-fouling agents.

This record suggests a performance which is fully up to the standard of that of the complete cementiferous scheme discussed in the preceding section. If, however, exposure is made for periods longer than that given in Table III, signs of deterioration appear during the second year of exposure. Table IV shows the extent of this deterioration for a paint scheme composed of a priming coat of E 412 followed by one coat of a proprietary anti-fouling paint. Rusting, which was negligible after one year's exposure, was heavy after a further year in the sea.

Further, if a paint scheme of this type is exposed for a year and then withdrawn, cleaned, and the anti-fouling coat renewed, although rusting may be slight or negligible at the end of the initial period of exposure, deterioration takes place more rapidly than usual on re-exposure, which suggests that although damage is not apparent at the end of one year it is nevertheless present and soon leads to further deterioration.

The experimental compositions used as anti-fouling coatings for these exposures have all contained rosin and can be described, following the terminology used by Ketchum, Ferry and Burns,[4] as anti-fouling compositions with soluble matrices. The American work just quoted indicates that for their effective action, sea-water must penetrate such coatings, and this is confirmed by the experimental work (as yet unpublished) carried out at Millport on this type of composition.

It is therefore evident that such anti-fouling coatings cannot be effective as sealing coats for long periods, as eventually it seems probable that sea-water must come into contact with the cementiferous primer. The exposure records of this type of cementiferous paint scheme bear out this indication. In some exposures of this type, contact between cementiferous primer and sea-water is hastened by flaking of the anti-fouling coating. In many cases this flaking seems to be the result of the appearance of small blisters in the priming coat; these are not dangerous in themselves and appear to be quite stable, but their eruption weakens the oleoresinous coating above them, leading to flaking of the latter coating.

Further, some exposures of cementiferous/oleoresinous anti-fouling-coat schemes have shown marked deterioration shortly after immersion. It is possible that this is due to the interaction of copper compounds in the anti-fouling coating with the zinc dust in the cementiferous undercoat.

All the records so far described in this section have referred to exposures below the water-line. If environmental conditions are made more rigorous by exposure at the water-line, deterioration is hastened and serious breakdown is evident after comparatively short periods of exposure. Table V gives the record of a water-line exposure of the paint scheme recorded in Table III; a comparison of these two Tables shows the more rapid breakdown under the more rigorous conditions obtaining at the water-line.

Protection was satisfactory during the first six months of exposure, but thereafter deterioration steadily progressed. Comparable control exposures of oleoresinous coatings (*i.e.*, one coat of oleoresinous protective composition; one coat of oleoresinous anti-fouling composition) were not made, but in view of the poor performance of such schemes when the anti-fouling paint was applied over *two* coats of an oleoresinous protective composition (*see* Table VII, p. 232), it seems fairly safe to say that the performance of this cementiferous scheme, though not as satisfactory as that of other schemes to be described in a later section, would be superior to that of a two-coat oleoresinous scheme.

Table V

PROTECTIVE PERFORMANCE OF A CEMENTIFEROUS/OLEORESINOUS ANTI-FOULING SCHEME (E 412; AF 337 M) EXPOSED AT THE WATER-LINE

Condition	Average Estimate after Exposure, % of area coated												
	14 days	29 days	57 days	91 days	121 days	145 days	183 days	209 days	248 days	274 days	303 days	334 days	372 days
Blistering	0	0	0	0	0	Tr	Tr	1·0(?)	Tr	Tr	1·5(?)	2·5(?)	2·5(?)
Flaking	0	0	0	0	0	0	0	0	0	0	0	0	0
Rusting	0	0	Tr	1·8	2·0	2·0	3·0	5·0	7·5	6·5	11·5	12·5	15·0

Table VI
PROTECTIVE PERFORMANCE OF THREE-COAT SCHEMES

Paint Scheme	Condition	Average Estimate after Exposure, % of area coated												
		14 days	29 days	57 days	91 days	121 days	145 days	183 days	209 days	248 days	274 days	303 days	334 days	372 days
E 412/ AC 173/ AF 337 M	Blistering	0	0	0	Tr	Tr	12·5	12·5	1·5	5·0	5·0(?)	7·5(?)	6·5(?)	10·0(?)
	Flaking	0	0	0	0	0	0	0	0	0	0	0	0	Tr
	Rusting	0	0	0	0	0	0	0	0	0	0	0	0	0
AC 173/ AC 173/ AF 337 M	Blistering	0	0	0	0	Tr	Tr	2·5	3·5	5·0	12·5	8·0	12·5	25·0
	Flaking	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rusting	0	0	Tr	Tr	Tr	Tr	Tr	Tr	Tr	1·0	2·5	4·0	6·5

Exposures of Schemes of the Type Cementiferous/Oleoresinous Protective/Oleoresinous Anti-Fouling Coat

The results recorded in the previous section suggest that efficient protection by a cementiferous/oleoresinous anti-fouling scheme is only temporary, and that extended exposure reveals a deterioration in performance over its later stages. The interposition of an oleoresinous protective coating between the primer and the anti-fouling coat, by providing a more effective ' seal ' for the primer, should therefore be advantageous. Unfortunately, exposures have not yet been made for a sufficiently extended period to prove this point conclusively, but there is a good deal of indirect evidence which would suggest that a three-coat scheme incorporating an oleoresinous protective coat is superior in performance to the two-coat schemes discussed in the previous section.

Table VI sets out the records of a three-coat scheme of the type just mentioned (the only difference from the schemes given in Tables III and V is the addition of one coat of the experimental anti-corrosive composition AC 173 ; for the formulation of this protective composition, *see* Fancutt and Hudson[5]), together with the records of the corresponding ' control ' scheme composed only of oleoresinous compositions.

Signs of deterioration in protection in the oleoresinous scheme appeared after nine months' exposure and the condition slowly deteriorated over the ensuing three months, whereas the protection afforded by the scheme based on a cementiferous primer has been complete for the whole period. Exposure is being continued, and it will be interesting to discover for how long this good performance can be maintained. Other evidence would suggest that it is likely to be maintained for some time, as a comparable scheme which was withdrawn after one year's exposure, re-painted, and again exposed, showed none of the early deterioration which characterized the two-coat schemes subjected to the same treatment and which were mentioned in the preceding section. This re-painted three-coat scheme shows only traces of rust after a further year's exposure.

Table VII summarizes the performance of the three-coat scheme under discussion, when exposed at the water-line ; the exposure records of the comparable oleoresinous scheme are again included.

It is evident that the performance of the cementiferous scheme is markedly better under these circumstances than that of the oleoresinous scheme, though it should also be noted that the performance of this particular three-coat cementiferous scheme at the water-line is no better than that of the corresponding two-coat scheme (*see* Table V, p. 231). This point is discussed further in the next section.

OTHER EXPOSURES OF CEMENTIFEROUS COMPOSITIONS

In the preceding sections an account has been given of the protective performance of paint schemes

Table VII
PROTECTIVE PERFORMANCE OF THREE-COAT SCHEMES AT THE WATER-LINE

Paint Scheme	Condition	Average Estimate after Exposure, % of area coated												
		14 days	29 days	57 days	91 days	121 days	145 days	183 days	209 days	248 days	274 days	303 days	334 days	372 days
E 412/ AC 173/ AF 337 M	Blistering	0	0	0	0	0	0	5·0	2·5	5·0	5·0(?)	10·0	5·0	10·0(?)
	Flaking	0	0	0	*Tr*	0	0	0	0	0	*Tr*	*Tr*	*Tr*	Tr
	Rusting	0	0	0	0	Tr	Tr	1·1	2·6	4·5	8·0	8·5	12·0	12·5
AC 173/ AC 173/ AF 337 M	Blistering	0	0	0	0	0	0	2·5	?	?	?	...	...	...
	Flaking	0	0	0	0	0	0	Tr	0	0	*Tr*	...	...	...
	Rusting	0	0	Tr	12·5(?)	22·5	25·0	27·5	30·0	45·0	75·0	...	...	...

In the flaking estimate, an estimate in italics indicates that at least a part of the flaking recorded involved both coats, primer and anti-fouling coat.

Table VIII

PERFORMANCE OF PAINT SCHEMES BASED ON CEMENTIFEROUS PRIMERS

Paint Scheme	Site of Exposure	Average Estimate after Exposure. % of area rusted			
		3 months	6 months	9 months	12 months
E 412 (Mg)/173/288 M[a]	Water-line	Tr	1·0	11·5	22·5
	Immersed	0	0	0	0
E 412 (Ba)/173/288 M[b]	Water-line	Tr	Tr	2·0	6·5
	Immersed	0	0	0	0
E 412 (Mg)/173/337 M	Water-line	0	1·1	8·0	12·5
	Immersed	0	0	0	0
E 412 (Ba)/173/337 M	Water-line	Tr	Tr	Tr	Tr
	Immersed	0	0	Tr	0
E 412 (Mg)/288 M	Water-line	10·0	15·0	50·0	85·0
	Immersed	0	Tr	Tr	2·5
E 412 (Ba)/288 M	Water-line	11·5	16·5	50·0	82·5
	Immersed	0	Tr	Tr	Tr (?)
E 412 (Mg)/337 M	Water-line	1·8	3·0	6·5	15·0
	Immersed	0	Tr	Tr	Tr
E 412 (Ba)/337 M	Water-line	1·5	4·0	12·5	20·0
	Immersed	5·0	10·0	10·0	10·0
E 390 (Mg)/173/288 M[a]	Water-line	Tr	2·0	7·5	11·5
	Immersed	Tr	Tr	3·5 (?)	9·0 (?)
E 390 (Ba)/173/288 M[b]	Water-line	Tr	2·0	4·5	6·5
	Immersed	0	Tr	1·0 (?)	1·5 (?)
E 390 (Mg)/173/337 M	Water-line	Tr	2·5	11·5	20·0
	Immersed	0	Tr	Tr	Tr
E 390 (Ba)/173/337 M	Water-line	Tr	3·5	5·0	9·0
	Immersed	0	0	Tr	Tr
E 390 (Mg)/288 M	Water-line	12·5	22·5	20·0	32·5
	Immersed	Tr	Tr	Tr	1·0 (?)
E 390 (Ba)/288 M	Water-line	3·5	12·5	12·5	15·0
	Immersed	Tr	Tr	1·3	1·3
E 390 (Mg)/337 M	Water-line	2·0	7·5	15·0	32·5
	Immersed	Tr	Tr	Tr	Tr
E 390 (Ba)/337 M	Water-line	1·5	6·5	8·0	12·5
	Immersed	Tr	1·1	2·5	5·0
173/173/288 M	Water-line	17·5	27·5	85·0	...
	Immersed	Tr	1·0	5·0	9·0
173/173/337 M	Water-line	12·5 (?)	27·5	75·0	...
	Immersed	Tr	Tr	1·0	6·5

a. E 412 (Mg) or E 390 (Mg) indicates that the cementiferous composition in question was made up using $MgCl_2$ solution as vehicle.
b. E 412 (Ba) or E 390 (Ba) indicates that the cementiferous composition in question was made up using $BaCl_2$ solution as vehicle.

wholly composed of, or based upon, the cementiferous compositions E 412 and E 390, using $MgCl_2$ solution as a vehicle. Emphasis has been laid particularly upon E 412 throughout so as to present comparable schemes for discussion, but it is now necessary to mention some variants of these schemes which have been tested during the past two years.

Some tests have been made of two-coat and three-coat schemes incorporating cementiferous compositions as the priming coat, in which the nature of the vehicle used in the cementiferous paint and the type of anti-fouling coat have been varied. In this series, cementiferous compositions E 412 and E 390 have been prepared using a saturated aqueous solution of $BaCl_2$ and a 22% aqueous solution of $MgCl_2$ as vehicles. Two experimental anti-fouling compositions, 337 M (containing cuprous and mercuric oxides) and 288 M (containing cuprous oxide) were used as the final coats.

The performance of these schemes is briefly summarized in Table VIII. The two-coat and three-coat schemes discussed in greater detail in the section on exposures of paint schemes based on cementiferous primers, were members of this series and are included in the Table.

An inspection of Table VIII emphasizes the points made in the preceding sections and also suggests one or two factors which seem to improve performance further. It is evident that the performance of three-coat schemes is better than that of two-coat schemes and it would also appear that the use of $BaCl_2$ as a vehicle produces a better performance than the use of a priming coat incorporating $MgCl_2$. Further, performance is generally better under a copper–mercury composition (AF 337 M) than under an anti-fouling composition containing cuprous oxide only (AF 288 M) ; this result may be due to differences in the film properties of these two types of anti-fouling paint. Finally, though the differences in performance between the two cementiferous compositions used in these exposures, E 412 and E 390, are not large, E 412 seems generally to have the the better performance, particularly in the three-coat scheme exposures. The painting scheme which combines all the favourable factors—E 412(Ba)/AC 173/AF 337 M—*i.e.*, barium chloride vehicle, three-coat scheme, and a copper–mercury anti-fouling coat, has an excellent performance, whether exposed at the water-line or fully immersed.

The results recorded in this Table also indicate an additional advantage in the use of a three-coat scheme. It will be seen that the performance of the scheme E 412(Ba)/AF 337 M, when fully immersed, is poor in comparison with the corresponding two-coat exposures similarly immersed. This indifferent performance seems to be due to some intrinsic incompatibility in this scheme rather than to any fault in painting or preparation of the exposure, as a repeat exposure has also deteriorated unusually rapidly. When an oleoresinous protective coat is introduced into the scheme, however, performance is improved to such an extent that, as has just been mentioned, this three-coat scheme has given the most promising results of any in the series.

These tests of cementiferous compositions have not been confined to exposures involving E 412 and E 390. In addition, tests of E 581 and E 378 as primer coatings have also been made. Exposures of these compositions have only been made as components of two-coat schemes ; Table IX outlines their protective performance over a 12-month exposure period.

Table IX

PERFORMANCE OF TWO-COAT SCHEMES BASED ON E 412, E 378 AND E 581

Paint Scheme	Average Estimate after Exposure, % of area rusted			
	3 months	6 months	9 months	12 months
E 412 (Mg)[a]/Proprietary-AF ...	0	0	Tr	Tr
E 412 (Ba)[a]/Proprietary-AF ...	0	Tr	Tr	1·5
E 378 (Mg)/Proprietary-AF ...	Tr	Tr	Tr	1·0
E 378 (Ba)/Proprietary-AF ...	0	Tr	1·0	2·0
E 581 (Mg) Proprietary-AF ...	0	Tr	1·0	1·5
E 581 (Ba)/Proprietary-AF ...	0	Tr	1·3	1·5

a. See note below Table VIII

These records suggest there is very little to choose between these three priming coats ; E 412 is perhaps the best but the differences between it and the other two compositions are too small to be of much significance. More extensive tests, along the lines of those made using E 412, have not been made with E 378 or E 581, but some preliminary water-line exposures of E 581 as a component of a two-coat scheme have indicated that its performance under these conditions is at least equal to that of E 412.

DISCUSSION

The observations recorded in this paper indicate that the use of cementiferous compositions as priming coats for a painting scheme otherwise composed of oleoresinous paints gives a paint scheme with a very satisfactory performance under raft-exposure conditions and suggest that more extended trials under service conditions should yield results of interest and importance. Tests of these compositions on ships have been begun but, as only two have yet been completed, it is too early to draw conclusions from their results. It can be said, however, that there is nothing in the results of service tests using these compositions which runs contrary to the results obtained from raft exposures.

It should be emphasized that a cementiferous composition can only be applied to a bare steel surface, and the use of these compositions as primers is therefore limited to the initial painting of the hull before launching or to occasions when extensive re-plating has proved necessary. A ' complete ' cementiferous painting scheme seems rather sensitive to the state of the steel surface, as the performance of

such a scheme is much better over a scaled than over a weathered surface. This disadvantage does not seem to apply if the cementiferous composition is used as the primer for a scheme otherwise oleoresinous in type, as tests of such schemes on pickled, weathered, or as-rolled panels give results which are equally satisfactory.

As has been mentioned previously, the pigment of these cementiferous compositions is mixed with the vehicle shortly before application. This disadvantage as compared with an oleoresinous primer is partly outweighed by the ease with which these cementiferous compositions are applied, and further outweighed by the fact that, as pigment and vehicle are separate until painting is about to begin, no deteriorative changes, such as settlement, can take place in these compositions. Tests have been made at Millport using a cementiferous composition made from pigment which had been stored for at least three years; its performance was fully equal to that of a paint made from freshly prepared pigment.

A suitable ship-painting sequence would be the application of one coat of a cementiferous composition followed by one coat of an oleoresinous protective composition, on the stocks. When in dry dock, after fitting out, a further coat of an oleoresinous protective composition should be applied, followed by an anti-fouling coat. Such a scheme, in which the cementiferous primer is sealed by two oleoresinous protective coats, should, on the basis of these results of raft exposures, prove an efficient protective scheme and an excellent basis for subsequent paintings.

The performance of suitable three-coat schemes incorporating a cementiferous primer when exposed at the water-line, seems especially to merit attention. The use of a cementiferous primer over the boot-topping region would seem to provide protection so effective that the anti-fouling paint used can be of the type normally only used under the water. Many anti-fouling paints for the boot-topping region fail to protect from fouling settlement because it is necessary, to avoid gross deterioration of the paint film, to use a varnish of a type unsuitable for the maintenance of an adequate leaching rate of the poisons contained in the paint. If a cementiferous primer is used, the risk of gross deterioration of the paint film is so much reduced that an anti-fouling composition formulated for under-water service can be used. This should allow more effective protection against fouling settlement at the water-line. It should be added that all the anti-fouling compositions used on the water-line exposures cited in this paper were of the normal under-water type; they were not specially designed for boot-topping use.

SUMMARY

Details are given of the results of raft exposures of paint schemes comprising cementiferous protective and cementiferous anti-fouling coats ('complete' cementiferous schemes) and of paint schemes incorporating cementiferous compositions as priming coats.

The addition of phenyl mercury acetate to a cementiferous composition produces a coating with an appreciable anti-fouling life and, though the protective properties of a 'complete' cementiferous paint scheme using such an anti-fouling coating are by no means negligible, 'wear' of the coatings becomes appreciable after roughly one year's exposure. This 'wear,' it is suggested, is to be expected in the light of the conclusions reached by Mayne and Thornhill.[1]

Overpainting a cementiferous primer with an oleoresinous anti-fouling paint furnishes a seal which is effective only for a limited period. The protective performance of such a scheme is good for periods of up to one year, but deterioration takes place if exposure is extended beyond this period.

The interposition of an oleoresinous protective coat between the cementiferous primer and the anti-fouling coat should provide a more effective seal and thus prolong the length of effective life of the schemes. Results so far obtained indicate that this suggestion is correct.

Minor variations in the constitution of two-coat and three-coat paint schemes based on cementiferous primers are described and some details are given of the performance of different cementiferous compositions when used as priming coats.

The practical application of these results of panel trials is discussed and emphasis laid on the use of paint schemes based on cementiferous primers for the boot-topping region.

Acknowledgments

The work described in this paper is merely a continuation of that begun on marine exposures of these compositions by Professor J. E. Harris, to whom the author is much indebted for his interest and advice at every stage of its development. Grateful acknowledgment is also made of the help received from Dr. U. R. Evans and Dr. J. E. O. Mayne. The assessments of these exposures have formed part of the regular programme carried through by members of the Millport team, and the author is much indebted to his colleagues, Mr. M. W. H. Bishop and Mr. W. R. Hunter, for their very considerable help in making these assessments.

References

1. J. E. O. Mayne and R. S. Thornhill: *Journal of The Iron and Steel Institute*, 1948, vol. 158, pp. 219–228 (this *Journal*).
2. J. E. Harris: *Journal of The Iron and Steel Institute*, 1946, No. II, pp. 297–333P.
3. K. A. Pyefinch: *Journal of The Iron and Steel Institute*, 1945, No. II, pp. 229–243P.
4. B. H. Ketchum, J. D. Ferry and A. E. Burns: *Industrial and Engineering Chemistry*, 1946, vol. 38, pp. 931–936.
5. F. Fancutt and J. C. Hudson: *Journal of The Iron and Steel Institute*, 1946, No. II, pp. 273–296P.

Surface-Temperature Measurement

By M. Diana Hedgcock, B.Sc., and R. Mayorcas, B.Sc.

SYNOPSIS

This report constitutes a survey of methods of measuring surface temperature which have particular reference to the requirements of the steel industry. The following points emerge :

(i) A pyrometer using a lead sulphide cell should prove particularly useful for temperatures in the range 100–500° C. Quite large variations in emissivity do not appreciably affect the calibration of the instrument.

(ii) The development of the photo-electric-cell pyrometer has been considerably advanced and the instrument can possibly be used in rolling-mill practice. The disappearing-filament pyrometer is also a suitable instrument for many rolling processes.

(iii) A contact pyrometer depending on the application of a refractory plug could be developed to give the true surface temperature of ingots in soaking pits.

(iv) The range of the compensated contact thermocouple can be extended to temperatures of 700° C. and this instrument can be made automatic.

(v) A satisfactory method of temperature measurement has been devised for use with furnaces for annealing fairly large castings.

Introduction

In 1944, the Thermal Treatment Committee of the British Iron and Steel Federation asked the Pyrometry Sub-Committee to investigate the problems of surface-temperature measurement in the steel industry, with particular reference to the conditions prevailing during mechanical working and heat-treatment.

During mechanical working, such as rolling, cogging, and forging, it is important that the metal temperature should not fall below a well-established point, while during soaking and annealing the rate of heating and cooling should be carefully controlled, particularly in the case of certain alloy steels. The surface temperature is the only unknown factor required for complete knowledge of the thermal state of the material, since the centre temperature can be calculated from this and the physical constants of the metal.

The range of temperature of steel-treatment processes is wide, extending from 150° C. for cold-rolling, through about 900° C. for annealing, to 1200° C. in soaking pits. In this range are included the temperature fall from 1100° to 700° C. in the cogging and rolling mills and forging temperatures of 800° to 1150° C. Some special steels have to be worked in the narrow range 400–600° C. and the tempering of large forgings requires temperatures from 250° to 350° C. No one technique of surface-temperature measurement can cover all these cases and, therefore, a comprehensive survey of all possible instruments is given, including a discussion on the possibilities of developing new approaches to the subject.

The temperature of a surface can be determined by its effect on some suitable physical property of a body either brought into contact with the surface or subjected to the radiation from the surface. These two methods are discussed separately.

THEORETICAL CONSIDERATIONS

RADIATION

The laws of spectral and total radiation from a surface both include an emissivity factor which is characteristic of the surface. The spectral emissivity, E_λ, of a surface is defined as the ratio of the amount of energy radiated by the surface at a given temperature over an infinitesimally small wavelength range

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Table I

SPECTRAL AND TOTAL EMISSIVITIES OF IRON AND IRON OXIDE ($\lambda = 0{\cdot}65\mu$)
(Data from Burgess and Foote[1])

Temperature, ° C.	Metal		Oxide		Observed Temperature of Surface at 1100° C. with Cold Surroundings, °C.	
	E_λ	E_t	E_λ	E_t	Optical Pyrometer	Radiation Pyrometer
800	0·381	0·05	0·98	0·87	1106	1060
900	0·380	at a	0·97	0·87	...	...
1000	0·379	temperature	0·95	0·88	...	...
1100	0·378	of 100° C.	0·93	0·88	...	...
1200	0·378	...	0·92	0·89	...	...

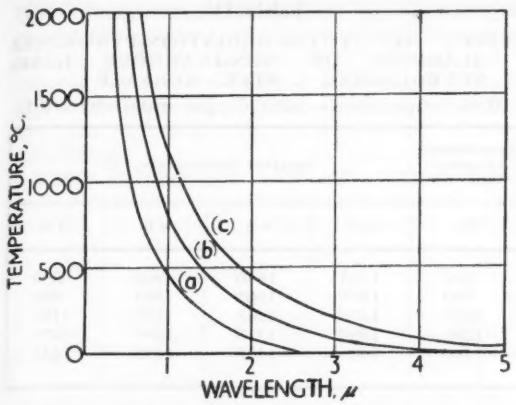


Fig. 1—Emissivity-wavelength/temperature curves for $\delta T/T = 1\%$ and (*a*) $\delta E_\lambda/E_\lambda = 20\%$, (*b*) $\delta E_\lambda/E_\lambda = 15\%$, and (*c*) $\delta E_\lambda/E_\lambda = 20\%$

λ to $\lambda + \delta\lambda$ and in a given direction, to the energy emitted by a black body under the same conditions. The total emissivity, E_t, is defined as the ratio of the total energy radiated by the surface at a given temperature to that radiated by a black body at the same temperature. Consequently, as is well known, all radiation and photometric pyrometers used for measuring surface temperatures are subject to errors which vary according to the emissivity of the surface concerned and the temperature of the surroundings.

Table I gives the spectral and total emissivity figures for clean iron and an iron oxide. They show the general and expected result that the oxide more nearly approaches a black body than does the clean metal surface and, in particular, in some cases the spectral emissivity is much nearer unity than the total emissivity. This suggests that an instrument such as the disappearing-filament pyrometer should give good results for many of the operations that a particular steel undergoes in its progress through a shop. The following analysis supports this supposition :

The energy J_λ radiated in the interval λ to $\lambda + \delta\lambda$ is given by :

$$J_\lambda d\lambda = E_\lambda c_1 \lambda^{-5}(e^{c_2/\lambda T} - 1)^{-1}\, d\lambda \quad \ldots\ldots(1)$$

To maintain a constant reading on an instrument measuring $J_\lambda d\lambda$ when E_λ changes to $E_\lambda + \delta E_\lambda$, demands a change in temperature δT where :

$$0 = \frac{dE_\lambda}{dT} + \frac{E_\lambda c_2}{\lambda T^2(1 - e^{-c_2/\lambda T})}$$

$$\therefore \frac{dT}{T} = -\frac{dE_\lambda}{E_\lambda} \cdot \lambda T(1 - e^{-c_2/\lambda T}) \quad \ldots\ldots(2)$$

$$\text{or } \frac{dT}{T} = -\frac{dE_\lambda}{E_\lambda} \cdot \frac{\lambda T}{c_2}$$

$$\text{since } e^{-c_2/\lambda T} << 1 \quad \ldots\ldots(3)$$

The curves (*a*), (*b*), and (*c*), of Fig. 1 have been calculated for $dT/T = 1\%$ and $dE_\lambda/E_\lambda = 20\%$, 15%, and 10%, respectively. They show that for measurements made with a disappearing-filament pyrometer (when $\lambda = 0{\cdot}658\mu$) there will be an error of only 1% in a temperature measurement made in the range 700–1200° C., even if the emissivity changes by 15%.

In many cases, however, a manually controlled instrument is inconvenient and there is no automatic optical pyrometer manufactured in this country.

The foregoing is an over-simplification of the problem, for although the oxide layer which usually exists on the steel provides a good emitting source, it also acts as an insulator because of its lower thermal conductivity. The data given in Table V show that under cooling conditions an oxide layer $\frac{1}{2}$ mm. thick with an assumed thermal conductivity of 10^{-3} c.g.s. introduces a temperature gradient of 320° C./in. at 1200° C., compared with a gradient of about 75° C./in. in the steel. The difference is probably increased by

Table II

INSULATING EFFECT OF OXIDE LAYER
(Data from Burgess and Foote[1])

Temperature of Metal Surface, ° C.	Temperature of Oxide Surface, ° C.
600	590
700	682
800	785
900	875
1000	950
1100	1015

Table III

EFFECT OF EMISSIVITY ON TOTAL-RADIATION AND OPTICAL PYROMETERS SIGHTED ON A STEEL SURFACE SURROUNDED BY WALLS AT 1470° C.
(Data from Cory and Reid[2])

True Surface Temperature, ° C.	Apparent Temperatures, ° C.					
	Total-Radiation Pyrometer			Optical Pyrometer		
	$E_t = 0{\cdot}5$	$E_t = 0{\cdot}95$	$E_t = 0{\cdot}99$	$E_\lambda = 0{\cdot}5$	$E_\lambda = 0{\cdot}95$	$E_\lambda = 0{\cdot}99$
38	1205	560	295	1390	1140	1010
540	1220	641	577	1390	1140	1010
815	1254	888	830	1391	1141	1013
1090	1320	1130	1100	1393	1160	1120
1370	...	...	...	1435	1380	1372
1430	1464	1432	1431	1455	1433	1431

the air gap which exists between the oxide and the metal surface.

Burgess and Foote[1] give the values in Table II for the average inner and outer temperatures of an oxide layer formed on a block of metal under standard conditions. The thickness of the layer is not given.

The correct measurement of the surface temperature of the oxide layer during re-heating processes does not then give the true temperature of the surface of the metal. Furthermore radiation methods of temperature measurement during re-heating are subject to error owing to reflection of radiation from hotter surroundings.

Table III shows that although the total-radiation pyrometer is more accurate than the optical pyrometer, there remains an error. The values in Table IV have been calculated to show that the presence of non-luminous or partly luminous flames adversely affects the total-radiation pyrometer, whereas the optical pyrometer is very little affected.

The curves in Fig. 1 show that at temperatures below 600° C. measurements should be made in the infra-red; in this range the lead sulphide cell is particularly suitable. A pyrometer based on these cells is being developed in the Physics Laboratory of the British Iron and Steel Research Association. Some typical cells investigated have given large changes in output for relatively small changes of temperature of the source under investigation. At temperatures above 800° C. it is necessary to make measurements in the ultra-violet part of the spectrum, which involves many difficulties.

Land has devised a surface pyrometer which is sensibly independent of the emitting characteristics of the surface, but experimental evidence of its accuracy and practicability is lacking at present.

Other methods of avoiding the effect of emissivity include the use of the simple colour pyrometer and its modification, the colour-brightness pyrometer. The latter instrument is only applicable to measurements on grey-body radiators the emissivities of which may be calculated from the colour and brightness temperatures. Unfortunately very few surfaces are in fact true grey-body emitters.

CONTACT METHODS

Contact methods of surface measurement usually involve the application of thermocouples either pressed or welded to the surface. It is essential to ensure that the measuring element does not disturb the heat-flow conditions and the temperature gradients at the surface.

A thermocouple junction placed at the surface of a hot body will not appreciably affect the radiant-heat loss in the region of application. But the heat loss by conduction cannot be neglected, since the wires have to be stout to ensure good thermal contact when the couple is pressed on to the surface.

In one method the conduction losses are reduced to a minimum by running the lead-in wires to the thermojunction along the surface to be measured. Many commercial instruments have been designed on this principle and for smooth continuous surfaces reasonably good results are obtained. An instrument of this type is recommended in the British Standards Code on temperature measurement, 1041 : 1943.[11]

A method has been devised[3] of compensating for the heat loss through thermocouple wires by surrounding a short length of the wires near the point of application with an adjustable heating element. A differential thermocouple measurement ensures zero heat flow from the surface ; thus if the area covered is very small compared with the surface to be measured, little or no error is introduced, and the true surface temperature is obtained. The range of this type of instrument has been extended to about

Table IV

EFFECT ON TOTAL-RADIATION-PYROMETER READINGS OF NON-LUMINOUS GASES SURROUNDING A STEEL SURFACE

(Wall temperature = 1400° C.; gas emissivity = 0·1)

True Surface Temperature, °C.	Apparent Temperature, °C.			
E_t:	0·6	0·8	0·9	1·0
320	1175	1040	960	850
500	1195	1065	985	890
1000	1275	1205	1170	1130
1200	1350	1315	1295	1275
1400	1435	1435	1435	1435

Table V

SOLID HEMISPHERE AND THERMOCOUPLE

Temperature, °C.		Emissivity of Oxide Layer	Difference in Temperature, °C.			Error, °C.
Surroundings	Steel Block		Across Oxide Layer	Between Oxide Layer and Centre of Thermocouple	Between Distant Point on Steel Surface and Centre of Hemisphere	
1500	1200	0·8	2·4	24	−23·4	3
		0·4	2·4	24	−11·7	12·7
1200	900	0·8	2·4	24	−14·4	12·0
		0·4	2·4	24	− 7·2	19·2
0	1200	0·8	−6·4	−64	8·0	−62·4
		0·4	−5·6	−56	3·0	−57·6
0	900	0·8	−4·5	−45	2·2	−47·3
		0·4	−3·8	−38	0	−41·8

700° C. by choosing suitable materials. However, the greater the gradient, the higher the input current required, and this itself can be a limitation. It is important to reduce the heat capacities of all these types of instrument to a minimum in order to reduce as much as possible the time required to reach equilibrium.

Where circumstances allow the simple contact method described by Elcock* may be used. For example, the annealing of large forgings or castings lends itself admirably to this technique and good results have been obtained. Thermocouples are placed in close contact with the surface and protected from the furnace atmosphere, remaining in the furnace throughout the annealing period. The maximum temperatures reached are about 900° C., and chromel–alumel thermocouples withstand the conditions well.

Another approach is to press the thermocouple on to the surface by means of a refractory plug. The thermocouple may be made from fine wires which are allowed to run along the surface within the confines of the plug ; in this way the conduction loss

* Private communication.

Table VI

SOLID HEMISPHERE AND THERMOCOUPLE EMBEDDED IN IRON DISC

Temperature, ° C.		Emissivity of Oxide Layer	Difference in Temperature, ° C.			Error, ° C.
Surroundings	Steel Block		Across Oxide Layer	Between Oxide Layer and Centre of Thermocouple	Between Distant Point and Centre of Hemisphere	
1500	1200	0·8	3·1	0·1	−23·4	20·2
		0·4	3·1	0·1	−11·7	8·5
1200	900	0·8	3·1	0·1	−14·4	11·2
		0·4	3·1	0·1	− 7·2	4·6
0	1200	0·8	−8·3	−0·2	12·0	− 3·5
		0·4	−7·3	−0·2	3·0	− 4·5
0	900	0·8	−5·9	−0·2	2·2	− 3·9
		0·4	−4·9	−0·1	0	− 5·9

Table VII

COMPACT CYLINDER

Temperature, ° C.		Emissivity of Oxide Layer	Difference in Temperature, ° C.			Error, ° C.
Surroundings	Steel Block		Across Oxide Layer	Between Oxide Layer and Centre of Thermocouple	Between Distant Point and Centre of Hemisphere	
1500	1200	0·8	2·5	25	−19·5	8
		0·4	2·5	25	−10	17·5
1200	900	0·8	2·5	25	−12·2	15·3
		0·4	2·5	25	− 6·1	21·4
0	1200	0·8	−6·7	−67	10·2	−63·5
		0·4	−5·9	−59	2·6	−62·3
0	900	0·8	−4·8	−48	1·9	−50·9
		0·4	−4	−40	0	−44

Table VIII

THERMOCOUPLE IN IRON DISC

Temperature, ° C.		Emissivity	Difference in Temperature, ° C.			Error, ° C.
Surroundings	Steel Block		Across Oxide Layer	Between Oxide Layer and Centre of Thermocouple	Between Centre of Disc and Distant Point on Iron Surface	
1500	1200	0·8	56·5	1·6	−9·1	49·0
		0·4	56·5	1·6	3·1	61·2
1200	900	0·8	35	1	−5·7	30·3
		0·4	35	1	1·9	37·9
0	1200	0·8	−56·5	−1·6	9·1	−49·0
		0·4	−56·5	−1·6	−3·1	−61·2
0	900	0·8	−21·6	−0·6	3·5	−18·7
		0·4	−21·6	−0·6	−1·2	−23·4

is greatly reduced. However, the plug disturbs the thermal-equilibrium conditions at the surface. For equilibrium at one temperature the plug may be made from a material such that the heat lost by conduction through the refractory is equal to the radiant-heat loss before the application of the plug. It should be possible to follow this simple technique further so that quite a wide range of temperatures, say 200° C., can be covered by any one contact thermocouple with a specific shape and insulating material.

When a surface is being heated and its temperature is required only when it is near the furnace temperature, the heat lost by the plug may be neglected in comparison with its shielding effect, and the refractory plug is equivalent to a perfect insulator. Land* has shown that for a perfectly insulating disc of radius d, the temperature at the centre of the disc is that which normally exists at a distance d within the surface, provided that the insulated area is small compared with the dimensions of the hot body. Readings taken alternately with insulating discs of different diameters would enable the temperature gradient at the surface to be calculated and hence the centre temperature to be determined.

In soaking pits there is often a thick layer of oxide on the ingots. The insulating effect of the refractory plug greatly reduces the temperature difference across the oxide layer, so that the reading of the thermocouple correctly interpreted can give a value close to the actual steel-surface temperature.

Tables V, VI, VII, and VIII, based on calculations by H. C. Plaut, indicate the errors with four shapes of refractory plug under different conditions. The conditions considered are :

(*a*) A steel block at 1200° C. surrounded by furnace walls at 1500° C.

(*b*) A steel block at 900° C. surrounded by furnace walls at 1200° C.

(*c*) A steel block at 1200° C. cooling to atmosphere.

(*d*) A steel block at 900° C. cooling to atmosphere.

The block is in each case covered by an oxide layer ½ mm. thick with a thermal conductivity of 3×10^{-3} c.g.s. and with emissivities of 0·4 and 0·8. The four types of pyrometer construction considered are :

(i) A solid hemisphere, 1·27 cm. in dia., of insulating material (thermal conductivity 3×10^{-4} c.g.s. and emissivity 0·5), with a thermocouple 1 mm. in dia. embedded at the centre of the base, with the lead wires running along the base so that the conduction along the wires can be ignored.

(ii) A similar solid hemisphere with a small iron disc 1½ mm. thick embedded in the centre of the base, with the thermocouple welded to the centre of the disc. The radius of the disc is supposed to be so small that it does not appreciably increase the heat conduction from the edge of the hemisphere to its centre.

(iii) A solid cylinder of the same material, 0·6 cm. high and 1·1 cm. in dia. The thermocouple is embedded in the base of the cylinder and the thermocouple lead wires are protected as in (i).

(iv) An iron disc of dia. 1·27 cm., thickness 1·5 mm., and an emissivity of 0·5, with the thermocouple embedded in it.

Tables V, VI, VII, and VIII show the results of calculations for the four pyrometers. The values in the fifth column of each table have been calculated to estimate the error which may arise if the contact between the oxide layer and the thermocouple is not sufficiently good to make the temperature of the couple equal to that of the surface. In calculating these values it has been assumed that the temperature at the centre of the thermocouple is the mean of the temperature of its surroundings. The diameter of the thermocouple has been taken to be 1 mm. and the mean temperature required is, therefore, that of the insulating material at a distance of ½ mm. from the surface of the base of the hemisphere. As the insulating material is supposed to have a conductivity one-tenth of that of the oxide layer, the temperature differences in column 5 work out to be ten times those in column 4 when there is no iron disc present. Column 6 gives the temperature difference in the steel block caused by the shielding effect of the insulating hemisphere on the radiation. Column 7 indicates the total error expected in using the pyrometer.

The results suggest that a thermocouple welded to a steel disc embedded in the refractory gives the greatest accuracy in all cases. This is mainly because the thermal contact between the thermocouple and the ingot is greatly improved by the steel disc.

The general problem of the calculation of the temperature gradients after the application of an imperfect insulator on an ingot having a thick oxide layer is being considered in detail. Work on this subject will be published at a later date.

METHODS OF MEASURING SURFACE TEMPERATURE

This section has been divided into four parts, namely :

(1) Optical Methods. (3) Contact Methods.
(2) Radiation Methods. (4) Other Methods.

The term " optical " has been used to embrace any technique which involves the matching of the spectral brightness of a surface with a controlled brightness. Methods which involve quantitative measurements of the radiation emitted, whether total or restricted to a given part of the spectrum, have been included under " Radiation." Part (3) deals only with the direct measurement of surface temperature by application of a thermocouple.

OPTICAL METHODS

The Disappearing-Filament Pyrometer

In the disappearing-filament pyrometer the intensity of radiation from a black body at a fixed wavelength is compared with that from a known source by viewing the two fields through a monochromatic filter. Since only the energy emitted in a narrow band of the visible spectrum is considered, the temperature scale is based on the Wien-Planck law :

$$J_\lambda = c_1 \lambda^{-5} e^{-c_2/\lambda T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where J_λ = the radiant energy at a wavelength λ,
T = absolute temperature, and
c_1 and c_2 are constants.

* Private communication.

Experiments have shown[2] that this formula is accurate to within 1% for temperatures as high as 4500° C., except at very short wavelengths, but since few bodies radiate maximum energy at a given wavelength (*i.e.*, are black bodies for this wavelength) equation (4) is modified to :

$$J_\lambda = E_\lambda \lambda^{-5} c_1 e^{-c_2/\lambda T} \quad \ldots\ldots(5)$$

where E_λ^s is the spectral emissivity of the body at the wavelength λ. The use of an optical pyrometer assumes a knowledge of the emitting power of the surface whereby corrections to the readings can be made.

The Polarizing Type of Pyrometer

A polarizing pyrometer was first constructed by Wanner[4] in 1901. As shown in Fig. 2 the light from a hot body passes through the slit at *V* ; the light from the comparison lamp is totally internally reflected in the prism, *P*, and then passes through the slit *W*. The two beams are rendered parallel by the lens *L*. Monochromatic light is produced by means of a direct-vision spectroscope and screen, cutting out all but a narrow band in the red. Each of the beams is next separated by a Rochon prism, *R*, into two beams polarized at right angles. A second achromatic lens focuses the beams on the slit, *D*, and a biprism, *B*, produces a deviation in the beams so that two images, one from each source, are brought into juxtaposition. All the other images are screened out. A Nicol analyser is attached to the eyepiece so that it can be rotated about the optical axis. If the two beams are of unequal intensity it can be rotated between 0° and 90° until the field is uniformly illuminated.

Later designs have introduced monochromatic filters instead of the spectroscope, but in both cases there is a great loss of light owing to the optical system used, and this prevents the measurement of temperatures below 900° C. A further disadvantage is the fact that light from incandescent surfaces is partially plane-polarized which, in some cases, may cause serious error.

The Bichromatic Pyrometer

The bichromatic pyrometer is an attempt to eliminate the emissivity factor which relies on the assumption that the variation in emissivity over a small range of wavelengths, say from red to green, is small and negligible. Thus, if an optical pyrometer is sighted on to a surface alternately through red and green filters, the temperature can be calculated from equation (5), suitably modified for different wavelengths :

$$\frac{J_{\lambda_1}}{J_{\lambda_2}} = \phi = \frac{E_{\lambda_1}}{E_{\lambda_2}} \left\{\frac{\lambda_2}{\lambda_1}\right\}^5 e^{-c_2/T\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)} \quad \ldots\ldots(6)$$

It is now known that the variation in the emissivity over a small wavelength range is not small enough

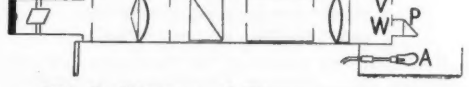


Fig. 2—Diagram of Wanner pyrometer

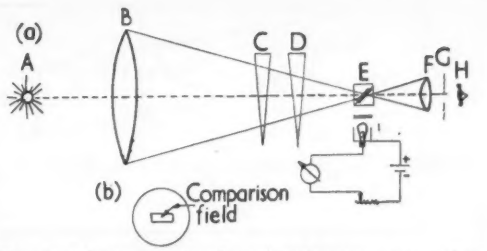


Fig. 3—Diagram of colour-brightness pyrometer

to be neglected, the difference being of the order of 2–5%. The ratio of the emissivities, however, is probably more constant.

The Simple Colour Pyrometer

For a grey-body emitter equation (6) becomes

$$\phi = \left(\frac{\lambda_2}{\lambda_1}\right)^5 e^{-c_2 T\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)} \quad \ldots\ldots(7)$$

If λ_1 and λ_2 are the wavelengths of complementary colours, then there is a definite ratio of intensities, Φ, necessary to produce white light. Therefore if the light from a grey body is passed through a wedge whose coefficients of absorption for wavelengths λ_1 and λ_2 are α_1 and α_2 respectively, then the body will appear white when viewed through a thickness d of the wedge such that

$$\Phi = \phi\left(\frac{1-e^{-\alpha_1 d}}{1-e^{-\alpha_2 d}}\right) \quad \ldots\ldots(8)$$

Since Φ, α_1, and α_2 are constant, the value of d will depend on ϕ, which in turn depends on the temperature of the grey body. It is therefore possible to calibrate the wedge in terms of the temperature of the body.

A simple instrument based on these principles has been devised and for physiological reasons the two monochromatic radiations in green ($\lambda_1 = 0{\cdot}525\mu$) and red ($\lambda_2 = 0{\cdot}703\mu$) are chosen. The pyrometer suffers from the defects :

(i) The measurement depends on the relative sensitivity of the observer's eye to red and green light.

(ii) No account is taken of the property of selective radiation, which very often results in a temperature reading which is higher than the true temperature.

The Colour-Brightness Pyrometer

The colour-brightness pyrometer[5] was designed to eliminate the defects mentioned above. As shown in Fig. 3, it consists of a telescope with objective lens *B*, eye-piece *F*, and diaphragm *G*. A bichromatic colour wedge, *C*, is placed in the path of radiation of the body the temperature of which is required. The grey wedge, *D*, reduces the brightness of the transmitted beam of radiation. The glass cube, *E*, silvered and cemented along a diagonal plane, brings the radiation from the comparison lamp into the same field of view as the main source. The light from the lamp is first filtered by a flat bichromatic plate which transmits only red and green wavelengths, in such a ratio that the resultant is white. The provision of this standard field of light with a similar spectral distribution to the field under observation is claimed to eliminate the defect of the human element.

The effect of selective radiation can be balanced for

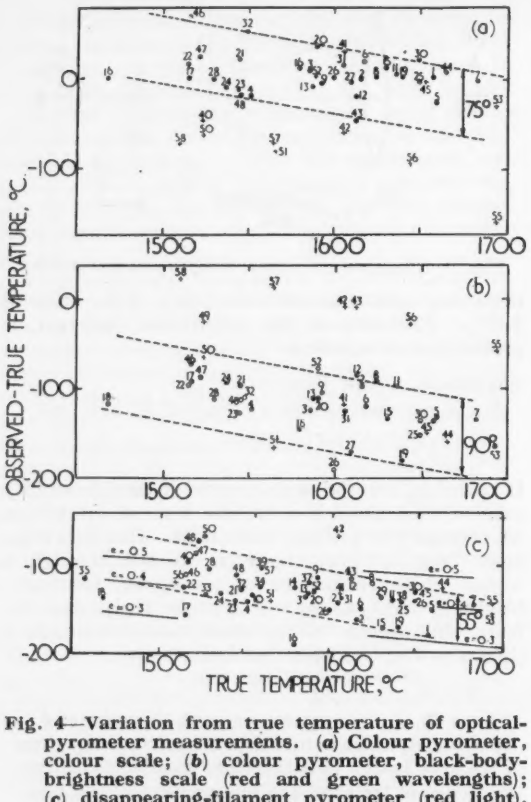


Fig. 4—Variation from true temperature of optical-pyrometer measurements. (*a*) Colour pyrometer, colour scale; (*b*) colour pyrometer, black-body-brightness scale (red and green wavelengths); (*c*) disappearing-filament pyrometer (red light). The numerals indicate the test number. Carbon steels are indicated by circles, alloy steels by crosses. (According to Todd[6])

a particular specimen by tinting the grey wedge. The colour temperature of bodies which are not black is therefore lowered. If this value is to be taken as the true temperature, the error with bodies emitting selective radiation is very often decreased. Bodies which already emit grey radiation give slightly lower readings than the true value.

Todd[6] of the Research Department of Messrs. Hadfield, Ltd., has carried out comprehensive trials of the colour-brightness pyrometer in the works and laboratory. The laboratory tests covered many different steels in the liquid state, the temperatures being measured with an immersion thermocouple and a disappearing-filament pyrometer in addition to a colour-brightness pyrometer. In Fig. 4 (taken from a paper by Todd[6]) the differences between the observed temperatures and the immersion-thermocouple temperatures for a number of carbon and alloy steels are plotted against the true temperatures, as determined by the latter instrument.

The colour-pyrometer data are given in Fig. 4 (*a*); in general the temperatures are quite near the true ones for half of the carbon steels investigated, the average difference being less than 10° C. over the temperature range explored. Data for all the carbon steels indicate that at temperatures of about 1500° C. the colour temperature is as much as 30° C. high and at 1700° C. as much as 30° C. low. With a few exceptions, the points fall within a temperature band about 75° C. wide.

Black-body-brightness temperatures in red and green wavelengths as measured with the colour-brightness pyrometer are plotted in Fig. 4 (*b*). In this case the points fall in a similar band of width about 90° C.

It can be seen that the colour-brightness pyrometer does not correct for variations in emissivity with wavelength, in general, although it does indicate true temperature for quite a large number of steels of varying composition and unknown emissivity.

In Fig. 4 (*c*) are shown the results obtained when using an ordinary disappearing-filament pyrometer operating with red light only. These fall in a band about 55° C. wide and about 120° C. lower than the true temperature. The most satisfactory agreement between observed and true temperature was obtained with a 1·8% carbon steel.

RADIATION METHODS

The Total-Radiation Pyrometer

The simplest form of radiation pyrometer consists of a thermojunction in a cylindrical tube. A set of two or more diaphragms limits the cone of vision from the source of radiation and the thermojunction is placed at the apex of this cone. A given temperature will raise the temperature of the thermojunction to a point of equilibrium determined by the surroundings. Thus, the e.m.f. of the thermojunction can be calibrated for a range of temperatures, and the magnitude of the e.m.f. depends only on the sensitivity of the receiving element. This limitation of sensitivity has determined the design of pyrometers. For instance, lenses or mirrors are used to concentrate the energy, thus increasing the temperature to which the energy-detecting element rises. With a large number of junctions, *i.e.*, a thermopile, or the use of alloys, a sufficient e.m.f. may be generated to operate automatic-recording potentiometers without amplification. This was the trend in Great Britain until a few years ago when the American lead of using high-speed automatic-recording potentiometers began to be followed.

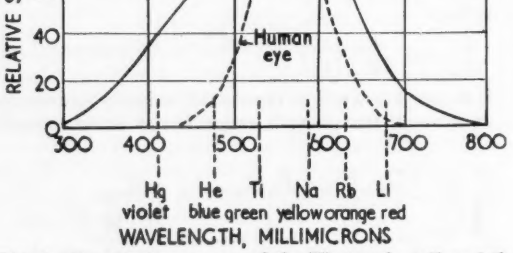


Fig. 5—Sensitivity curves of the Photronic cell and the human eye. (Weston Electrical Instrument Corporation)

The Photo-Electric Pyrometer[7]

The current produced by the release of electrons from photo-sensitive metallic surfaces can be used as a direct measure of the radiant energy received by the surface. The most promising types of photo-electric cell for temperature measurement are the barrier-layer cell and the caesium vacuum cell.

(a) *The Barrier-Layer (or Self-Generative) Cell*—In the barrier-layer cell a layer of non-conducting sensitive material is spread on a metal plate and covered by a very thin, transparent layer of distilled gold. A beam of radiant energy falling on this surface will pass through the transparent gold layer and fall on the non-conducting layer. This will cause a separation of electrons, and if the layer of gold and the metal base are connected a current will flow from one to the other. This current is approximately proportional to the radiant energy at the particular wavelength.

The sensitivity of the cell varies with wavelength and it is interesting to compare the sensitivity curve for a Photronic cell with that of the human eye (Fig. 5).

(b) *The Caesium Vacuum Cell*—The caesium vacuum cell is sensitive to the red end of the visible spectrum and to the nearby part of the infra-red (*see* Fig. 6). The spectral-sensitivity curves vary from cell to cell, probably owing to the presence of impurities.

A thin layer of caesium is deposited over a coating of silver on the inside of an evacuated glass bulb. When a beam of radiant energy falls on the mirror-like surface of the alkali metal, electrons are released which are converted into a current by applying a potential of about 90 V. across the terminals of the cell. The current produced is of the order of a few micro-amperes but can easily be ampified to milli-amperes for operating recording instruments.

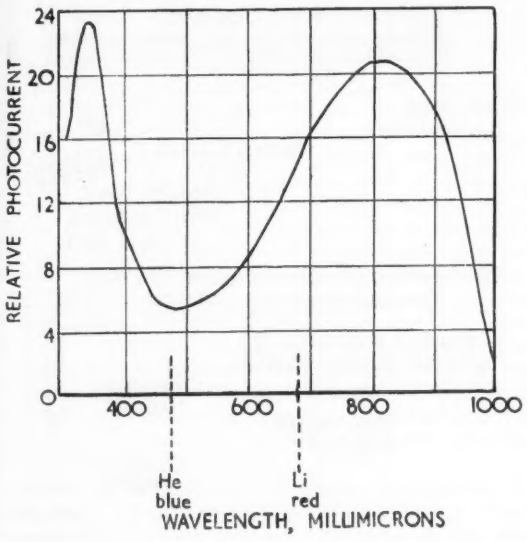


Fig. 6—Sensitivity curve of caesium/caesium-oxide/silver cell (L. R. Koller)

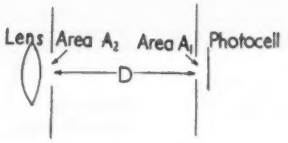


Fig. 7—Diagram of typical photo-electric pyrometer

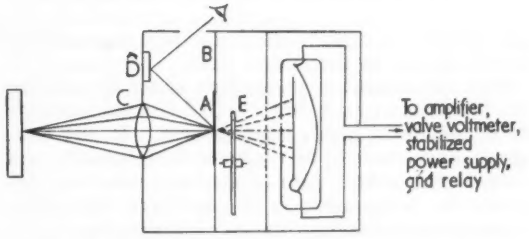


Fig. 8—Brown-Firth photo-electric pyrometer

A typical photo-electric pyrometer[8] consists of a cell, a lens, and two apertures, the latter to define the area of the cell exposed and the solid angle subtended by the lens at the cell (Fig. 7).

Land[9] has shown that the cell current depends on the factor A_1A_2/D where A_1 and A_2 are the areas of the lens and cell apertures respectively, and D is the distance between them. The size of the two apertures to produce a given current when sighted on a black body source of given temperature can be determined.

A pyrometer which measures the radiation from a hot body with one of these types of cell (the caesium type) has been developed in the Brown-Firth Research Laboratories. It has been designed primarily to measure the temperature of high-speed steel being heated by high-frequency induction. As the area of the hot surface is small and as the pyrometer must not be too near the H.F. field, an objective $\frac{1}{8}$ in. in dia. and at a distance of 10 in. is used.

An image of the hot body, *A*, (Fig. 8) is formed on an etched screen, *B*, with a hole in it, by a convex lens, *C*. This image is focused by viewing it through a plane mirror, *D*. Just behind the screen is a disc, *E*, which is divided into 16 sectors with the alternate ones cut out so that, when the disc is rotating at about 25 r.p.s., it interrupts the radiation at a frequency of 200 cycles/sec. In this way, the cell output, which normally would be insufficient to work an indicator or relay directly, can be amplified by a stable audio-frequency amplifier of high gain.

A Radiation Pyrometer in the Far Infra-Red

A pyrometer measuring the emission of energy in an isolated band of wavelengths at 8·8μ has been described by Strong.[10] The radiation is isolated by successive reflections from quartz crystals. The residual-ray apparatus used to isolate the band is compact and designed to avoid aberration. Owing to the polarization of the near infra-red radiations, it is more effective than earlier models of residual-ray apparatus in eliminating the undesired short waves. The band of radiation used by the instrument falls in a region where the atmosphere is very transparent.

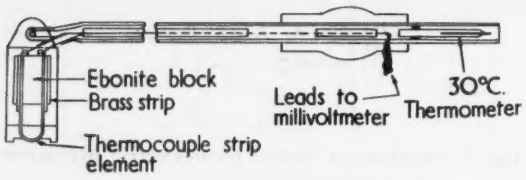


Fig. 9—Diagram of strip thermocouple

Accordingly, in most applications there is practically no absorption in the optical path.

This instrument is particularly suited for working the temperature range 0° C. ± 100° C. and is unlikely to be utilized at higher temperatures. In any case, the readings have to be corrected for emissivity and little seems to be known of the latter effect on this particular instrument. It is considered that some valuable work could be done in this direction.

CONTACT METHODS

The technique of sighting optical pyrometers down, or inserting thermocouples in, small holes bored in the surface of hot metals is well known, but since ingots, bars, billets, etc., are the final products of the steelmaking industry, it is obviously not practicable to use this technique for them.

Welded Thermocouple

An ideal, but again not very practical, method of measuring true surface temperature is to weld a thermocouple into the surface. With small-diameter wires, the conduction from the thermojunction may be made negligible. Though this method has been applied successfully to non-ferrous metals, it has been found unsatisfactory for steel, probably because of the unsuitability of the thermocouple materials at the high temperatures encountered.

Commercial Strip Thermocouple

The strip thermocouple (Fig. 9) consists of two thin strips of thermo-electric material which are butted and brazed to form the " hot " junction. These strips are looped so that the junction projects about $\frac{1}{16}$ in. beyond the level of the supporting legs. Compensating leads of the same material as the strips connect the latter to copper leads in the handle of the instrument, where a thermometer gives the temperature of the " cold " junction.

Another strip thermocouple consists of pieces of copper and constantan wire 0·1 in. thick and 0·25 in. wide welded together " end on " and supported between spring holders. When pressed against a smooth surface, the thermocouple conforms to the shape of the object so that about 4 in. on either side of the junction are in intimate contact with it. This reduces the heat conduction along the wires to a minimum. When the temperature of a flat surface is measured, a spring plunger carrying a pad presses the thermojunction into good contact with the body.

Several years ago Larsen[12] calibrated a surface pyrometer, which was adapted from this commercial strip thermocouple, for the purpose of investigating the cooling of rails. The thermocouple consisted of chromel and alumel wire welded together. The strip was polished, leaving the junction line barely visible so that the best possible contact could be made. The couple was stretched between the ends of a bow spring. Extension leads of chromel and alumel wire welded to the ends of the strip were brought out through a hollow handle of aluminium tubing 4 ft. long. The junction was pressed down by a narrow wedge cut from a porous fireclay insulating brick, shaped to fit the surface and insulating the strip for a length of 2 in. on both sides of the junction.

Under cooling conditions, it was found that at temperatures above 750° C. (inversion point of steel) the surface pyrometer read the true temperature fairly accurately, but that below this temperature the readings were 10–20° C. too high because of the insulating effect of the refractory wedge when recalescence caused the temperature to fall less rapidly than above the inversion point.

Compensated Thermocouple

The principle of the compensated thermocouple was described in the literature in 1932.[3] It has been applied in various ways and for a variety of types of observation in which the surface temperature of a material exposed to the atmosphere was required to be measured. The original instrument consisted of two base-metal thermocouples (Fig. 10). The contact thermojunction was spherical, with a small flat surface for good contact with the surface investigated. The conduction loss along the thermocouple wire was reduced to a minimum by means of an auxiliary heating coil wound round these conductors at a suitable position beyond the junction. The temperature gradient along the wires was observed by a second thermocouple, the thermojunction of which

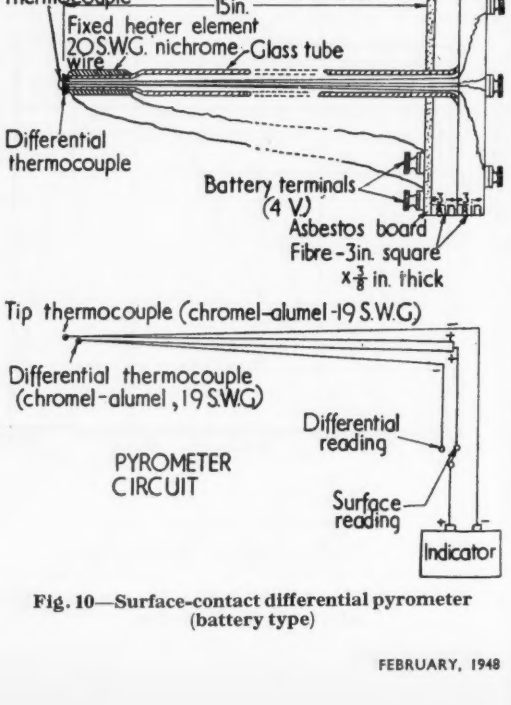


Fig. 10—Surface-contact differential pyrometer (battery type)

was placed as near as practicable to the elements of the first couple at a point near to the junction. The method was to raise the temperature of the contact couple by means of the heating coil to a value approaching the anticipated temperature of the surface to be explored. As the temperature gradient along the couple was accordingly reduced to a low value and the capacity of the contact couple low, the latter rapidly attained a temperature very nearly approaching the true temperature of the surface. Adjustment of the heating current after the first trial allowed of a still more accurate approach of the temperature of the contact thermocouple to the surface.

Instruments constructed on this principle, with various modifications in the method of compensating for the heat conduction into the contact head, have been in repeated use for many purposes at surface temperatures of up to 700° C. It is not desired in this type of instrument to measure higher temperatures as other methods are more convenient.

Simple Contact Method

Elcock of the English Steel Corporation, Ltd., has developed a technique in the heat-treatment of large masses of steel at temperatures of up to 900° C. The chromel–alumel thermocouples employed are made up of 8 B. & S. gauge wire, primarily insulated with twin-bore insulators of fireclay 1 in. long, and the whole covered with asbestos cloth, to give the necessary flexibility in passing from the steel to the outside of the furnace. Compensating leads run from the head of each thermocouple to multipoint recording apparatus conveniently fixed in the vicinity of the furnace. The usual procedure is to place the hot junction on the surface of the metal and press a piece of angle iron or similarly shaped material on top to make the best possible contact, and to cover the whole with fireclay. Contact thermocouples of this kind can be used in the manner described on the top and bottom of solid forgings. It is important, however, that the temperature at the centre of the forging should also be known and in experimental work this has been achieved by inserting a thermocouple in a hole $\frac{1}{2}$ in. in dia., bored to the centre of the forging along the longitudinal axis ; the results obtained are recorded simultaneously with the temperature given by the top and bottom thermocouples and a sheathed thermocouple suspended in the furnace as near to the steel as is possible. When equilibrium is reached in the furnace, the furnace and top thermocouples are at a slightly higher temperature, in general, than the bore and bottom thermocouples, the overall difference being about 20° C. A knowledge of the time when equilibrium of the mass is reached is important, since a saving in fuel consumption and maintenance can be achieved and at the same time the risk of defects in the steel caused by premature removal from the furnace, *i.e.*, when non-uniform temperature distribution still exists, is avoided.

The contact technique described above cannot be employed where higher temperatures, such as those required in soaking pits, are concerned, at any rate on a permanent basis, since the conditions governing such temperatures, which are usually in the region 1100–1500° C. would cause thermocouple contamination and mechanical failure and thus prevent accurate temperature determination.

OTHER METHODS

Thermocolours

" Thermocolours " is the name given to a series of powders which are claimed to have the property of changing their initial colour immediately that they reach certain temperatures. These thermocolours have either one or more colour changes and are dependent on time. The colour changes of the powders painted on a heated body indicate its surface temperature.

Only some of these thermocolours return to their initial colour after cooling, while other paints which are not reversible indicate the highest temperatures attained by the body. Some are partly reversible, returning to their original colour when moistened. Although there are many of these thermocolours, none can be used above a temperature of 800° C.

Earlier work on temperature measurement by chemical colour change is to be found in a paper by E. Schumacher[13] which describes how the application of lead carbonate to the surface of a hot plate may be used to determine its temperature. The following temperature–colour changes are given :

Temperature °C.	Colour
Up to 230	White
230–380	Brown
380–450	Red
450–570	Yellow
Above 570	Vaporizes.

Tempilstiks

Tempilstiks are in the form of crayons with fixed melting points. A mark with a Tempilstik on a surface whose temperature is to be measured will liquefy and virtually disappear when the surface reaches the melting point of the crayon. Each Tempilstik is coloured differently to make it possible to follow the rise in temperature of a hot surface. For example, the crayon which melts at 52° C. is light brown, and the one which melts at 66° C. is light green. At the present time, the highest temperature which can be measured with Tempilstiks is about 925° C.

NEW AND RECENT DEVELOPMENTS

The Lead Sulphide Cell Radiation Pyrometer

The lead sulphide cell is a photo-conductive semiconductor having the property of undergoing an almost instantaneous resistance change when exposed to infra-red radiation and is most sensitive to wavelengths between 1μ and 2μ. One type of cell consists of a thin film of lead sulphide sublimed into an evacuated pyrex envelope containing a suitable tungsten and " Aquadag " electrode assembly.

The cell may be used as one element of a sensitive balanced D.C. bridge, the out-of-balance potential obtained upon irradiation of the cell being used to deflect a sensitive galvanometer, or after passage through a D.C. amplifier, to drive a suitable meter. However, in view of the difficulties of D.C. amplification of small signals, and of the inherent tendency of the resistance of cells to " drift " it has been found

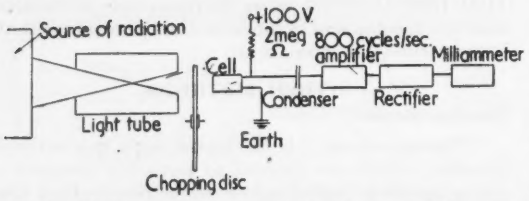


Fig. 11—Diagram of apparatus using lead sulphide cell

that a more satisfactory technique is to modulate or "chop" the incident radiation and amplify the resulting A.C. signal by means of a tuned amplifier.

The experimental equipment consists of a light tube with diaphragms to define the cone of radiation, a rotating chopping mechanism, the cell as part of a potential-divider chain, a tuned amplifier and rectifier, and an indicator or recorder. The arrangement is shown diagrammatically in Fig. 11.

Experimental results from three specimen cells may be summarized as follows:

(i) Minimum detectable temperature of a "black body" source was about 200° C. (The small diameter of the black-body source available limited the solid angle of radiation to a narrow pencil, with consequent reduction in threshold sensitivity.)

(ii) Readings in the range 200–350° C. were reproducible to within 3 or 4°.

(iii) Within the range 200–350° C., cell response, S, can be expressed very closely by the relation $S = KT^n$, where T is the temperature of the black-body source and n is of the order 8, but varies from cell to cell.

The Land Surface Pyrometer

A perfectly reflecting hemisphere with a small hole at the azimuth emits black-body radiation at the temperature of the surface to which the base is applied, whatever the characteristics of the surface.

By making the hemisphere of pyrex or *ON*19 glasses, which absorb practically all infra-red radiation, and silvering the outer surface, only visible radiation is reflected back to the hot surface. Hence, the radiation emitted at the small area of unsilvered glass is very nearly total radiation for the visible region of the spectrum.

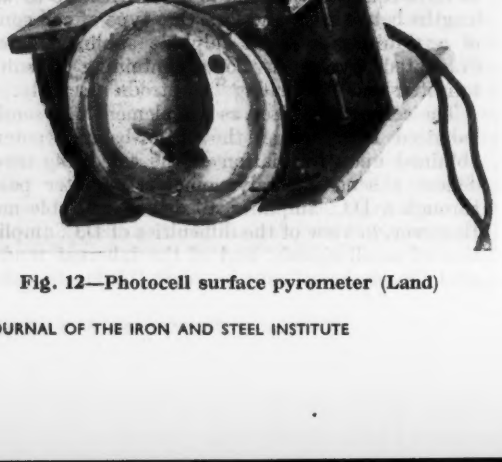


Fig. 12—Photocell surface pyrometer (Land)

Land has constructed a laboratory model of a pyrometer based on this principle (*see* Fig. 12) and has conducted a few preliminary experiments. The glass hemisphere, obtained by cutting the bottom off a round-bottomed flask, is held in a framework of Sindanyo asbestos board. The hemisphere is about 7 cm. in dia. and there is a gap of about 2 mm. between the hot surface and the glass. The radiation is measured by a selenium barrier-layer photo-electric cell which enables readings to be taken within a few seconds of contact, so that the glass does not become excessively hot and crack. Although for pyrex glass at 800° C. about 25% of the total radiation is reflected back to the surface, and at 1200° C. about 50%, the time of contact of the reflector is so short that the reflected radiation should not disturb the radiant-heat loss from the surface.

The use of glass for the hemisphere can be eliminated by absorbing the infra-red radiation with a simple sheet of *ON*19, placed at the base of a hollow polished-steel hemisphere which can be water-cooled. Thus, the only part of the pyrometer subject to damage from heat can be replaced cheaply and quickly.

The "Optimatic" Pyrometer

For most purposes a distinct disadvantage of the disappearing-filament pyrometer is its dependence on manual operation. A fully automatic optical pyrometer designed in America and called the "Optimatic" has been described by Sosman.[14]

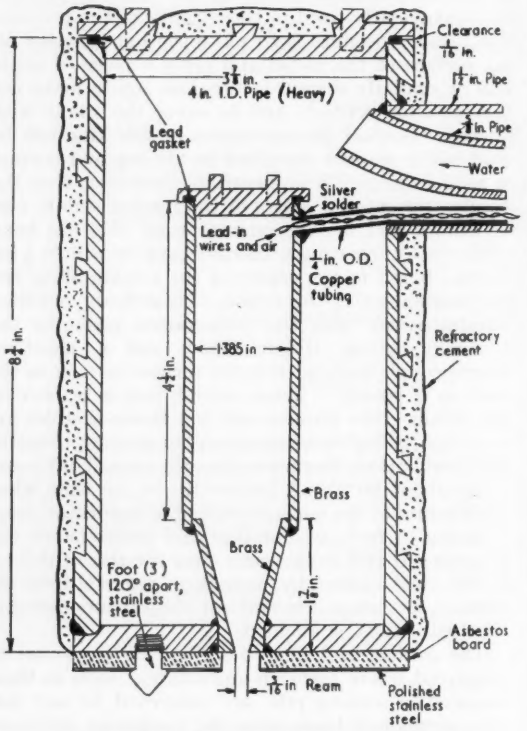


Fig. 13—Surface radiation pyrometer

Two vacuum photocells are illuminated by two sources of radiation, namely, the surface under investigation and the filament of a comparison lamp. Any difference in the output of the two cells is applied to an amplifier which automatically adjusts the current in the filament until a brightness match is produced. The current in the filament is a measure of the source temperature and can operate a suitable recorder. Although this is a considerable improvement on the original pyrometer it must be borne in mind that it is designed for a specific purpose, *i.e.*, the continuous recording of one source, whereas the portable manually operated optical pyrometer has the advantage of selection over any area required and is therefore much more suitable for checking purposes.

Improved Compensated Thermocouple

A method which has been suggested for applying the principle of the compensated thermocouple in order to obtain a record of surface temperature is as follows : One of the thermocouple wires, say the alumel wire of the chromel–alumel couple, is in the form of a stout rod about $\frac{1}{8}$ in. from the end. The chromel wires are insulated from this rod by fine drawn silica sheaths, and all three wires surrounded by a very thin alumina sheath, with alumina powder to pack the spaces. A nichrome wire is wound around the alumina sheath and the whole encased with some suitable covering. Adjustment of the heating current can be made automatic in the same way that a recording potentiometer adjusts the out-of-balance E.M.F.

Surface Radiation Pyrometer

This instrument[15] (Fig. 13) consists of a head about 9 in. long and 4 in. in dia. attached to a long handle. The radiation from the surface whose temperature is to be measured passes through an orifice containing a lens into a radiation tube. The reading is transmitted to a potentiometer by wires running through the handle. The head is water-cooled inside its steel and brass jacket and the working surface is made of polished steel backed by asbestos and stands on three small stainless-steel legs.

The pyrometer is claimed to measure successfully surface temperatures up to about 1300° C., its accuracy being about $\pm$ 3° C. if the radiation tube is kept within the temperature range 25–45° C.

CONCLUSIONS

The processes in which accurate surface-temperature measurements are required can be divided into two distinct categories, as follows :

(i) Those in which the surrounding walls and gases are at a higher temperature than the object to be measured.

(ii) Those in which the object radiates heat more or less freely to the atmosphere.

In the first category radiation and colour methods are not likely to give satisfactory results. Interference caused by gases adversely affects the readings of total-radiation pyrometers, and if the gases become luminous the photometric type of instrument is useless. A radiation unit mounted in the head of a water-cooled probe may be used, although the measurement of the surface temperature of a thick oxide layer is of doubtful value. The Elcock method is entirely suitable for annealing furnaces but it is not a practical proposition to instal permanently a thermocouple in the soaking pits. In the soaking pits the most reliable method is to press a thermocouple on to the ingot surface by means of a water-cooled spring in compression against a refractory plug.

Radiation methods are most suitable for processes in the second category, especially for those in which the metal is travelling at high speed. The lead sulphide cell pyrometer is especially suitable for cold-rolling, and may also be useful for some special forging processes. At higher temperatures the disappearing filament pyrometer is one of the most accurate instruments and is insensitive to small changes in emissivity. Therefore an automatic optical pyrometer might find considerable application. It is claimed that in American rolling mills this type of pyrometer has been used successfully in conjunction with a high-speed recorder. It is subject to the same geometric conditions as the total-radiation pyrometer and so similar difficulties in installation may arise.

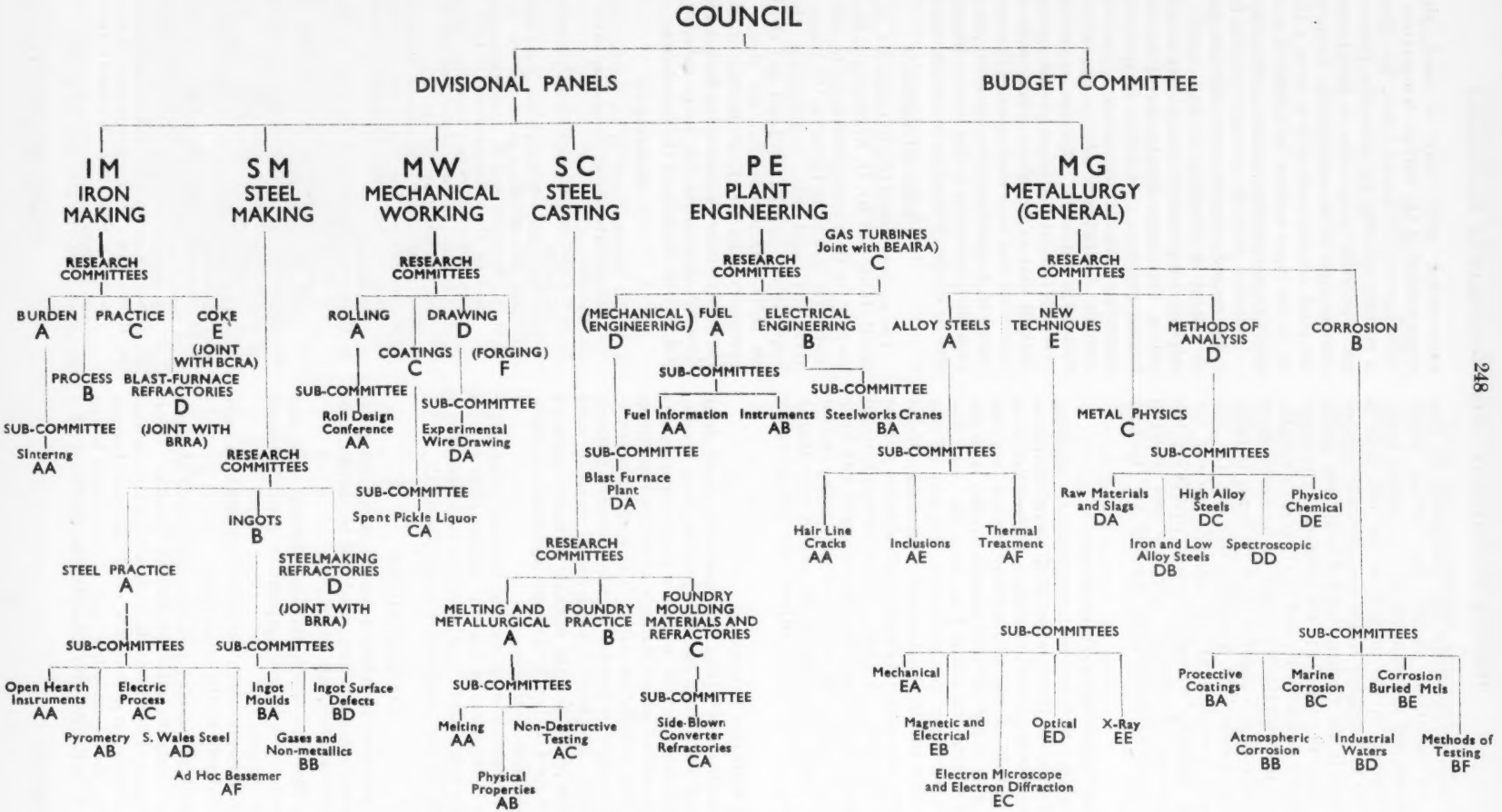
Acknowledgments

The authors would like to thank Mr. E. W. Elcock, Mr. P. Jubb, and Mr. D. Knowles and Professor R. J. Sarjant, for their contributions on the contact thermocouple for annealing furnaces, the photo-electric cell pyrometer, and the compensated thermocouple, respectively ; also Mr. T. Land and Dr. H. C. Plaut for their contributions on the theory of contact pyrometry, and Mr. E. J. Burton of the Heat and Thermodynamics Section of the British Iron and Steel Research Association for many valuable discussions and careful checking of the calculations.

References

1. G. K. Burgess and P. D. Foote : *Bulletin of the National Bureau of Standards*, 1915, vol. 12, pp. 91–178.
2. R. C. Cory and W. T. Reid : *Combustion*, 1944, vol. 15, p. 30.
3. R. J. Sargant : *Transactions of the Ceramic Society*, 1932, vol. 31, Mar., p. 86.
4. G. K. Burgess and H. Le Chatelier : "Measurement of High Temperatures," 1912, New York : John Wiley and Sons ; London : Chapman & Hall.
5. G. Naeser : *Journal of the Institute of Fuel*, 1939, vol. 12, Mar. ; pp. 38–41.
6. W. J. Todd : *Metal Treatment*, 1939, vol. 5, p. 171.
7. R. Sosman : "The Pyrometry of Solids and Surfaces," p. 22. 1940, Cleveland : American Society for Metals.
8. H. Lund : *Journal of Scientific Instruments*, 1947, vol. 24, p. 95.
9. T. Land : *Journal of The Iron and Steel Institute*, 1944, No. I, p. 481p.
10. J. Strong : *Journal of the Optical Society of America*, 1939, vol. 29, Dec., pp. 520–530.
11. "Temperature Measurement," pp. 55–56: British Standard Code No. 1041, 1943 : British Standards Institution.
12. R. Sosman : "The Pyrometry of Solids and Surfaces," p. 53. 1940, Cleveland : American Society for Metals.
13. E. Schumacher : *Gas-und-Wasserfach*, 1938, vol. 81.
14. R. Sosman : "The Pyrometry of Solids and Surfaces," p. 63. 1940, Cleveland : American Society for Metals.
15. *Steel*, 1946, vol. 119, Dec. 30, p. 74.

THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION



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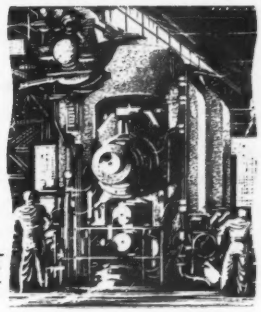
IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FIFTH MEETING

THE FIFTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 26th November, 1947. Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), Chairman of the Group, presided.

AT THE MORNING SESSION a paper on "The Mechanical and Electrical Features of Hot-Rolling-Mill Auxiliaries" was introduced by the authors, Mr. W. W. FRANKLIN and Mr. P. F. GROVE. The proceedings of this session will be published in the March issue of the *Journal*.

AT THE AFTERNOON SESSION a paper on "Modern Small Rolling Mills" was presented by the author, Mr. G. A. PHIPPS. The discussion, which is given below, was introduced by Mr. N. C. Lake.

PROCEEDINGS OF THE AFTERNOON SESSION: 2.0 P.M. to 4.30 P.M.

Discussion on MODERN SMALL ROLLING MILLS*

Mr. **G. A. Phipps** (Messrs. Guest, Keen and Nettlefolds, Ltd.) presented his paper, "Modern Small Rolling Mills."

Mr. **N. C. Lake** (The Head Wrightson Machine Co., Ltd.): Mr. Phipps made reference to ideal working conditions. This morning Mr. Grove advocated improvements in general painting and lighting in rolling mills. We have recently converted some old buildings to form a new machine shop, and have painted all machines and buildings in light attractive colours. The general results have been most remarkable and the effects upon the workmen have been very marked.

Would Mr. Phipps tell us whether in his recent visit to U.S.A. he saw any rolling mills and their buildings painted in the pleasant colours being used today in some industries in this country.

At the risk of being thought facetious, I would like to refer to Mr. Phipps' remarks on p. 249 about the increase in output per man. We are all bemoaning the fact that outputs per man are going down at present, and I should like to know whether Mr. Phipps accounts for the increase referred to in his paper as being the result of extra effort on the part of the men or improvement in organization or plant.

On p. 256 of the paper, I think there is a correction necessary. In line 8, the paper refers to 2-high stands, but I think it should be 3-high stands. I should like to be corrected on that point if I am wrong.

In reading through the paper I have noted that in almost every example illustrated, the billet shears are placed after the furnace instead of, as is customary in this country, before the furnace. I wonder whether this is done to enable smaller shears to be used, because they are to be cutting the hot material, or whether the idea is to enable the full furnace width to be used rather than to use a miscellaneous length of billet passing through the furnace. What is the reason? It seems to me that if we split the billet after heating, the second part must wait a little while on the table while the first is being dealt with, and as a consequence there is a risk of considerable temperature variation between the two pieces being rolled. Are the mills which are illustrated rolling a preponderance of special steels, and is it this factor which makes it necessary to put the shears after the furnace?

Figure 10 refers to a 3-high mill with tilting tables on which the majority of sections are given five passes, and it is stated that two sections are often in the mill at one time. I do not see how this can be done really effectively and efficiently with a 3-high

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 247–261.

mill. I am assuming driven rollers on the tilting table.

I have examined this matter and find that to operate as Mr. Phipps suggests will involve the introduction of the following piece at alternatively the third and fifth passes of the previous pieces on the following basis :

Pass 1 on piece 1 is in the forward direction.
Pass 2 on piece 1 is in the reverse direction.
Pass 3 on piece 1 is in the forward direction.

Here we introduce piece 2.

Pass 4 on piece 1 and pass 2 on piece 2 are in the reverse direction.
Pass 5 on piece 1 and pass 3 on piece 2 are in the forward direction.

Piece 1 is now complete and we have to complete pass 4 on piece 2 in the reverse direction before introducing piece 3 in its first pass, whilst pass 5 on piece 2 is in progress.

There does seem to be no other way of operating if we are to avoid one piece passing underneath the roller table whilst another is on the top.

The two pieces in the mill must necessarily be of different lengths, one having had more work upon it than the other. If the tilting table rollers are driven as I have assumed, then the shorter piece must move further from the mill to enable the longer piece to clear the mill before the table can be tilted and the rollers reversed. There is bound to be loss of heat on the earlier passes on this account. Would Mr. Phipps tell us whether in view of all these factors, the rolling of two pieces in a 3-high mill on a 5-pass programme is really justified ?

I have noted an almost entire absence of skew **Y** tables in the mills illustrated in Mr. Phipps' paper, and that all the heavier examples indicate side transfers. We have mills in this country working on skew **Y** tables on quite small sections, and I should be glad to know from Mr. Phipps why the Americans have adopted straight transfers in preference to skew **Y** tables. Is it on the score of increased efficiency ?

On p. 257, Mr. Phipps refers to looping troughs split down the centre and open about their centre line, the opening and closing of which are automatically controlled by the load in the exit motor. Would Mr. Phipps please give us a little more explanation of the operation of these troughs ?

Mr. **G. A. Phipps** : Mr. Lake mentioned ideal working conditions and the painting of mills in the United States. This matter has been given full consideration on the more recently installed wide strip mills, but I have not seen, or heard of any special features of this nature in connection with small hot mills.

With regard to increased production per man, this is accounted for by improvement in the type of labour available, by improved furnace conditions, and a better incentive system of payment ; all these factors have led to a corresponding increased productivity per man.

The point of the billet shears being positioned after the furnace is to enable the full furnace width to be used for the heating of the billets. Although the second part of the billet is held on the roller tables for a very short period of time, the temperature variation between the front and back end of the billet is very small. It should also be noted that where shears are installed the minimum size of billet sheared is usually 4 in.

The operation of two pieces in a 3-high mill with tilting tables is generally in accordance with the scheme as outlined by Mr. Lake, and, whilst the length of the piece at the various passes differs, the whole mill output depends entirely on the tonnage rolled in the roughing mill, as after the roughing mill usually only one pass is taken in the succeeding stands of rolls. The operation of two pieces in the roughing mill results in approximately a 50% increase in output from the mill, which fully justifies the use of this method.

As to skew tables, in the case of the bar and strip mill illustrated, skew tables are provided, as they are also on the 15-in. mill. Skew tables with the correct type of mill are the best solution, but generally with the other types of mills illustrated there is no point in using them.

With regard to the looping troughs, as soon as the load on the motor following the trough builds up to an adjustable pre-set value, a current relay completes a solenoid circuit, which in turn mechanically opens the trough.

Mr. **J. A. Thornton** (B. Thornton, Ltd.) : There is one historical point to which I would like to draw attention. George Bedson, the inventor of the so-called Morgan continuous mill, did start off with horizontal-vertical rolls. It should be known that a man who was the grandfather of the present Mr. Bedson used vertical rolls, which now are again being developed.

He also, I believe, in his original invention included the use of twist guides in his last pass.

Mr. **H. Scholey** (English Steel Corporation, Ltd.) : I speak from the point of view of those who have small mills of the type not described by Mr. Phipps. We come from the Sheffield area, and one of the points that arises in our minds is this. Would the type of mill that Mr. Phipps is describing—this is where I am seeking some sort of comparison—handle the wide variety of special steels that we have to deal with, where the factor of spread is so variable ?

When Mr. Phipps was talking of the alteration in the passes it seemed to me to be a case of fixed passes or reductions, and these had to accommodate the spread that arose in the particular material that was going to the mill. In order to get rid of that it was necessary to blunt the edge of the ovals somewhere to reduce this tendency to spread.

Having to deal with the wide range of smaller quantities and seeking also to incorporate the ideas that are embodied in these continuous mills, and to make use of them as far as we can, we are concerned to do so without losing the advantages we have in dealing with small quantities, and also in accommodating the varying conditions which arise through the wide range of compositions dealt with.

Mr. **G. A. Phipps** : The purpose of the blunt-edged oval is not so much for varying classes of steel as

for preventing rolling defects in the steel, such as the pinching of the oval at the bottom of the square pass which definitely produced seams in the material. The oval-edging-oval method definitely does get rid of that pinching, but the spread is roughly the same, and this method of reduction was not developed with the object of controlling spread. I quite agree that if you try to put a number of special steels, particularly alloy steels, through a rod mill without individual motor drives, you would have difficulty with a number of the qualities. We have put through the rod mill, without any difficulty, straight carbon steels containing up to 0·85% carbon, and a few low-alloy steels, but we have not rolled high-alloy steels.

Mr. **H. Scholey** : I would like to ask a further question. I have already put it to Mr. George, an old friend of mine. I was concerned also about the production of say, silicon–manganese spring steel, where we have to finish the section with a concavity of 4/1000. These sections are so thin that we find considerable wear on the camber of the roll producing them. I do not know whether there is evidence that the Americans roll this kind of thing to the degree of accuracy that is called for here, and whether they are using the continuous type of mill to do it, or whether they are having to turn in the same direction as we are, namely, a more general purpose cross-country type of mill.

Another thing to which we are giving considerable attention is the production of the shapes Mr. Phipps mentions in his paper. I take it that these are preformed shapes ready to go to a drop stamp.

Mr. **G. A. Phipps** : Spring steels in the United States are produced in continuous mills with open stands, and productions of 150–250 tons per shift are obtained. I have no information as to the accuracy of the finished product, as I have never investigated this problem.

Mr. **R. A. Lake** (Lancashire Steel Corporation, Ltd.) : I would like to ask Mr. Phipps whether any of these small mills have water-lubricated roll-neck bearings, and if so, whether he has experienced difficulty in re-starting after stopping the mill, at weekends, and so on. If so, does he know of any way of overcoming the difficulty ?

Mr. **G. A. Phipps** : I have never been concerned with that type of bearing. The only knowledge I have is the fact that on mills with this type of bearing they do, when shutting down, inject either grease or oil on to the neck so as to give an easy start. Whether that is a solution or not, I could not say.

Mr. **H. J. Knight** (Shell-Mex-B.P., Ltd.) : With regard to the remark about fabric bearings, I have some experience in that direction, and I have found it is a very great advantage to inject a water-soluble lubricant on to the roll-neck of the bearing before shutting down and before starting up. That has been proved, I think, in quite a number of mills where fabric bearings have been employed not only on the smaller rolling mills, but even on large reversing blooming mills.

If the water supply is operating on a closed system, or for reasons of contamination it is undesirable to utilize a water-soluble lubricant, other special lubricants can be employed to assist in overcoming starting torque and preventing incipient corrosion of the roll necks.

Mr. **F. B. George** (Consett Iron Co., Ltd.) : In reply to Mr. Scholey's query, we have as a matter of fact rolled both plain carbon spring steel and silicon–manganese spring steel on a straight continuous mill. Admittedly we have not rolled very large quantities at one time, so I could not answer definitely the question about the wear of the rolls, but you have to remember that on a mill of this type the finishing temperature is very much higher than on the old traditional type of mill, and the finishing temperature does not appear to affect the quality of the finished spring. Owing to the higher temperature, we do not run up against the same trouble with roll wear as we do on the slower type of mill. However, we have not rolled large enough quantities at one time to be able to answer the question definitely. Certainly, we have had no trouble with what we have rolled.

As far as the rolling of alloy steel on the continuous type mill is concerned, it is very largely a question of the alloy that you are rolling. If it is within a range where its behaviour at rolling temperature is not unlike that of ordinary carbon steel, I think you will have no trouble whatsoever. If you come to the very-high-alloy steel, stainless and so on, then owing to the temperature at which you have to roll and also owing to the very large spread it is quite likely that you would run into considerable trouble with the continuous type of mill unless the roll passes were specially designed. That would, of course, mean that you would have to schedule those particular types of steel to be rolled at the one time and to avoid excessive roll changes.

For example, in the roughing passes of a continuous mill, when rolling rounds you may have reductions of 40%, and have to get out of the pass a very flat oval in order to get the total number of reductions required in the number of stands available. It is essential to carry these heavy reductions, unless you are going to start with a very small billet. They might cause difficulty when rolling very-high-alloy steels, but I do not think that you would have difficulty in rolling the normal type of steel. The whole secret of production, of course, in any mill—it does not matter what type of product you are rolling—is large lumps : not only large lumps of steel going into the mill, but large lumps of the same product. In a continuous mill where you have to put the steel through a number of stands in succession, obviously you must have larger quantities of the one size in order to avoid excessive roll changing, because the roll changing takes longer than in the old type of mill.

The secret of the production success of large slabbing mills in the United States is to be found in the very large ingot used. It is possible they are not rolling any more ingots per shift than many mills in this country, but they are rolling 20 tons, perhaps, in each ingot instead of 7 tons, 7 tons instead of 2 tons, and so on. The same applies to the small mill ; there they are rolling a 30-ft. billet 2 in. sq., against a 5-ft. billet 2 in. sq., or a 30-ft. 6 × 2-in.

slab against a 7-ft. 6 × 2-in. slab. It is obvious that we are doing the same amount of work for about one-sixth of the production.

I have had experience on the old type of 12-in. mill, rolling 10 tons of ½-in. rounds in 8 hr., and the modern type of continuous mill rolling 17 or 18 tons/hr. of the same size, and I can say that the product of the high-speed mill is not only as good as, but considerably better than, the product of the low-speed mill. I suppose our continuous mill was probably the last to be installed in this country, since it only commenced production during the war.

There was one point Mr. Phipps made that I would like him to answer. He said, in respect of the bar and strip mill, that he thought many products in the mill made it uneconomic. I would like to know the reasons for that statement. Is it that the mill, being designed for so many products, is not as efficient for each individual product as it would be if it were designed as a speciality mill, or is it because of the difficulty of getting the mill crews to handle so many different types of product ? That is the trouble we have found up to date—not so much the design of the mill for the different products, but the difficulty of accumulating sufficient experience in the mill crews to handle the different types of products. They run for perhaps two weeks on angles, and then switch over to strip, and by the time they go back to angles, after two or three weeks of strip, they seem to have forgotten how to roll them.

I do not mean that to be taken literally, but nevertheless it is a difficulty. We keep complete records of every roll setting, and the roller has his card on which everything is put down—the roll speeds, the roll settings, the guide settings, and so on—but you still have that certain amount of human experience which leads a man to know where to look when something goes wrong. Anybody can roll in a mill when everything is going right. When you see a continuous mill working, you wonder how on earth it ever goes wrong, and when you see it going wrong, you wonder how you will ever get it right again. That is where the human experience counts—in knowing exactly where to go when trouble starts.

If Mr. Phipps could tell us why he thinks he had too many products in that particular mill, I should be obliged, because I think we have one more in ours. We are getting up to 300 tons a shift on angles and flats, and 250 tons a shift on strip. I do not say that happens on every shift, but we have produced in eleven shifts over 3000 tons of light flats, so we feel that we have not too many products. The only fear we have is in regard to this matter of experience, which in time we feel the crews will get over. A year's experience on a single-section mill is a year's experience, whereas if you have five or six products, it is only two months' experience.

Mr. **G. A. Phipps** : I fully agree with Mr. George's remarks regarding the difficulty of training crews to remember exactly what they did on the previous occasion. It is quite a difficulty on a mill with a number of products to train a crew, and it takes a very long time to do so, as we have found out. The strip side is difficult, and it does take time ; the bar side is easier ; but in the early days of operating a new mill, when you are changing over, you do find that on the first few shifts after starting, difficulties crop up, particularly in the setting of the mill. It is only time that can put that right, and switching the mill over as often as possible, so that the mill crew does not lose the knack of setting the mill.

The reason for the statement that the bar and strip mill produces more products than is economic is that a continuous mill should operate sixteen or seventeen shifts per week, and roll changing should only be carried out at weekends. The production of coiled products, owing to the existing handling facilities, reduces the average output per shift of the mill, and midweek changes are also occasionally required to roll these products ; it is for these reasons that reference was made to the subject.

Mr. **N. L. Tunbridge** (English Steel Corporation, Ltd.) : I am speaking from the point of view of the Sheffield steel trade and bearing in mind Mr. George's remarks about the " large lumps " that are desirable for successful rolling in the continuous mill, and the condition that in our trade, although we have not got these " large lumps," we do have fairly substantial quantities of a size.

I would like to ask Mr. Phipps what are his views on the type of mill, possibly a compromise between the continuous mill and the older type of hand jobbing mill at present in use in Sheffield, which would be an improvement on present practice, but always keeping in mind the relatively small quantities of work available in this country in the alloy steels, spring steels, and so on.

Mr. **G. A. Phipps** : The answer is the mill described in the November issue of the *Journal*, pp. 447–452, and that is the section mill of the Darlington and Simpson Rolling Mills, Ltd. This mill is as good an example as we have in this country, for the production of small quantities at good production rates. My own opinion is that mills based on this design, but modified according to the products required, would be most useful in the Sheffield area.

The **Chairman**: I would like to put a question to Mr. Phipps. He says on p. 259 that the 14-in. cross-country mill illustrated in Fig. 14 has really too high a production rate for this country, but it is not a really very-high-production mill, apparently, compared with what Mr. Phipps is already doing in some of his own mills.

When is a cross-country mill the right thing to use ? When would he use more individual drives and presumably, therefore, be able to go more straight-away ?

Mr. **G. A. Phipps** : The 14-inch cross-country mill is capable of producing 40,000 tons a month, whereas the mills we are operating produce about 10,000–14,000 tons a month. Personally, I cannot see any company putting such a high-production mill down in this country, with such a limited range of products, and I would venture to suggest that no sales manager would be capable of filling an order book to operate such a mill economically.

To answer Mr. Cartwright's query regarding the use of the cross-country mill or a straight-away mill with individual drives would require a paper in itself. Both types of mill have their uses, and it is only by a complete analysis of the products to be rolled in the mill that it is possible to decide on the type of mill that should be installed.

Mr. **T. W. Hood** (The United Steel Companies, Ltd.): My thoughts are running along similar lines to the previous question, but the answer does not quite give me the information I am looking for.

In high-production continuous merchant mills the accepted practice seems to be to have a tandem roughing train followed in most cases by a cross-country finishing train. I was interested to see that, in addition, two of the mills described have 3-stand tandem finishing trains, giving an excellent product.

I would like to ask why these mills have a cross-country train between the tandem roughing and tandem finishing trains.

Mr. **G. A. Phipps**: The point there is that the tandem train widens the range of the mill. That is the main point, I think. You are limited in output on the smaller sizes, and it is only by installing a tandem mill that you can widen the range. The thoughts in this country are always on widening the range of a mill, and that appears to be the best solution for increasing the range of a mill and still obtaining an economic production from it.

Mr. **T. W. Hood**: I appreciate the advantage of having a tandem finishing train, but I am not quite clear why cross-country stands are included between such a finishing train and a tandem roughing train.

Mr. **G. A. Phipps**: Certain sections cannot be rolled in a straight-away mill, hence the necessity for a cross-country section between the continuous roughing and a single or tandem finishing mill.

The **Chairman**: I think that Mr. Hood and I both mean the same thing—if you look at Fig. 14 you will see that there is one motor driving four stands through gear boxes, and another apparently driving six stands through gear boxes. Then comes one motor driving two stands, and then another motor driving another stand, followed by three individual drive motors. It would seem at first sight that the mill would have been much cheaper and just as good if the first six stands had had individually driven variable-speed motors followed by all the rest of them also individually driven by variable speed motors, thus cutting out all transfer tables and long troughs and roller gears. I think that what Mr. Hood and I do not understand is why you should put in all the elaboration of transfer tables if a variable individually driven motor would be just as good.

Mr. **G. A. Phipps**: The answer is that this mill was put down in, I think, the 1926–28 period, and individual drives had not been developed at that time to the stage which they have reached today. Also the roughing and cross-country stands are driven by comparatively cheap A.C. motors, whereas to drive the mill with individual driven variable-speed D.C. motors would have considerably increased the capital cost of electrical equipment of the mill.

The **Chairman:** Is it your view that the cross-country mill is dead ?

Mr. **G. A. Phipps**: No, the cross-country mill is not dead ; it still has its uses, and for certain products is still the best type of mill that can be installed.

Mr. **H. Scholey:** Having heard so much about high-production mills, it seems to me that there will be an upper ceiling to the number that will fit into our total steel economy in this country. Obviously, someone will have to determine where and when that position is. That is one of the things that has gone through my mind quite a lot recently when I have read of what we are all planning to do, or thinking of what we would like to do. There is bound to be a ceiling to their total economic usefulness.

Mr. **E. Hallas** (Brightside Foundry and Engineering Co., Ltd.): With reference to the merits of the continuous mill compared with the cross-country mill I think members present might like to have some further details of the Darlington plant, briefly referred to by Mr. Phipps.

An efficient cross-country type of mill, well laid out, would meet the rolling problems which Mr. Scholey and Mr. Tunbridge have referred to. The question as to the most suitable layout of either type is largely one of output and the range of products to be rolled. The continuous mill has its limitations in regard to the range of products, particularly in the case of shape rolling. In the case of the cross-country mill the arrangement depends somewhat on the ability to turn the piece by mechanical means or by hand or whether the piece has to be run straight out at each rolling pass after initial forming.

The new Darlington mill has a wide range of flexibility in speed and size of product which may be rolled. A great deal of thought was given as to the most suitable type of roughing mill and it was finally decided to instal a 2-stand 16-in. 3-high roughing unit with a D.C. variable-speed motor, the idea being to obtain as wide a range as possible of billet sizes and maintain a high rate of production. A limited number of passes are taken in the first stand and the billet is then transferred across to the second stand, which is fully mechanized. This arrangement enables two billets to be rolled at the same time. In the case of the intermediate and finishing mills it is not possible to turn the piece from stand to stand during rolling either mechanically or by hand, as the range of light sections which is being produced on this plant calls for the piece to be run straight out from each stand.

The 12-in. intermediate finishing mill is a three-stand dummy 3-high set-up in which a single pass is taken in each of the three intermediate stands. A separately driven 12-in. single 2-high finishing mill is arranged in line with the intermediate train and there is also a further No. 2 finishing mill separately driven and off-set to receive the bar for the finishing pass. All these units are separately driven by D.C. variable-speed motors.

The Darlington plant was designed primarily for high outputs of precision hot-rolled light sections and the intermediate and finishing mills are fitted with rolls mounted on heavy-duty roller bearings. This arrangement of roll mounting together with the correct type of roll has produced very large shift tonnages within the limits of accuracy called for. The wide range of products for which this mill is scheduled called for a number of change stands to reduce standing time. The change stands are completely fitted up ready for installation in the mill and this system removes one of the main objections to the employment of roller bearings for the roll necks.

Another interesting feature is that the roller bearings and chocks are left intact on the roll necks during re-grooving of the rolls and throughout the whole of the roll life.

This brief description outlines a few fundamental features desirable for the efficient rolling of alloy and special steels and in my view increased outputs may be obtained with a suitable cross-country layout for the production of a large proportion of special steel requirements rolled to close limits in the hot state.

Mr. **W. P. Snedden** (British Timken, Ltd.): I would like to add a little to what the previous speaker said. Where precision and speed are necessary, I think it is advisable to take as much adjustment out of the rollers' hands as possible. If you are going to have precision, build as much precision into the mill as you can at the beginning, and retain that precision by retaining the same bearing on the roll neck throughout its life. If your chocks and bearings are maintained, then your pass alignment is purely a matter of redressing in the roll lathe.

The **Chairman:** There has been a fairly wide range of discussion, and the paper covered a very wide range of subjects. It is the sort of paper which is needed at this moment. When we are doing so much planning, as Mr. Scholey said, and when everybody is thinking about how many mills we shall build, it is important for somebody to think how much steel we are going to roll. We must make sure that we have enough billets to go into the mills. If a mill built in 1926 produces, as Mr. Phipps said, 40,000 tons a month, presumably if we built one straight-away with variable speed motors all the way down and put it up today, I suppose that it would produce 60,000 or 70,000 tons a month. That would quickly overhaul our whole economy. It is very important from the large planning angle for the steel trade of Great Britain to make people think about what they are going to do in this very important trade of the small rolling mill.

DESCRIPTION OF PLANT

Merchant-Bar and Wire-Rod Mill at the Dalzell Steel Works, Motherwell

THE merchant-bar and wire-rod mill at the Dalzell Works of Colvilles, Ltd., was installed about ten years ago. Whilst it is not capable of attaining the high productions possible on some of the more recently installed mills of similar type, it is, nevertheless, of particular interest in view of its flexibility and the relatively high outputs obtained with comparatively simple means. The mill is also of considerable local significance, as it was the first mill in Scotland to incorporate the continuous system of rolling.

The mill, the layout of which is shown in Fig. 1, was laid down for the production of bars $\frac{5}{16}$–$1\frac{1}{4}$ in. in dia. in straight lengths, wire rods down to 5 gauge, and bars up to $\frac{7}{8}$ in. in dia. in coils. Production of finished material averages 1500 tons per week. Individual shift production is influenced by the size and class of product but, as an indication of the possibilities of the mill, it may be stated that on a quite normal shift's work covering $7\frac{1}{2}$ hr. rolling time, 175 tons, or approximately 900 billets, have been rolled into $\frac{27}{32}$-in. dia. bars with a finishing-pass efficiency of 68%.

The plant comprises a billet storage yard, a continuous reheating furnace, a seven-stand continuous roughing mill, a twelve-stand intermediate and finishing mill (of which the first six stands are arranged in pairs, staggered, and the remaining six stands in train) rotary flying shears, a mechanical cooling bank, cold-shearing equipment for straight lengths, three laying reels for rods, and two pouring reels for bars; a hook-type cooling conveyor for coiled material is also provided. Particulars of the various roll stands and drives are given in Table I.

The power supply for the mill is received at 11,000 V., 3 phase, 50 cycles, and is converted to 460 V. D.C. by three 750-kW. rotary converters, of which two or three are in commission, depending on the load demand of the mill. A 230-V. D.C. supply is available for specific duties, the rotary converters being of the 3-wire type.

The mill is supplied from larger mills with billets $1\frac{15}{16}$–$3\frac{1}{2}$ in. square and 15 ft. long, which are stored in a billet yard of 80 ft. span and 250 ft. long. The billets are handled by a 10-ton magnet crane, which transfers them from the incoming rail cars to stock piles and from thence to an inclined feed bench serving the continuous reheating furnace. This is of the side charging and discharging type, 17 ft. wide inside the walls and 35 ft. long, and fired with raw

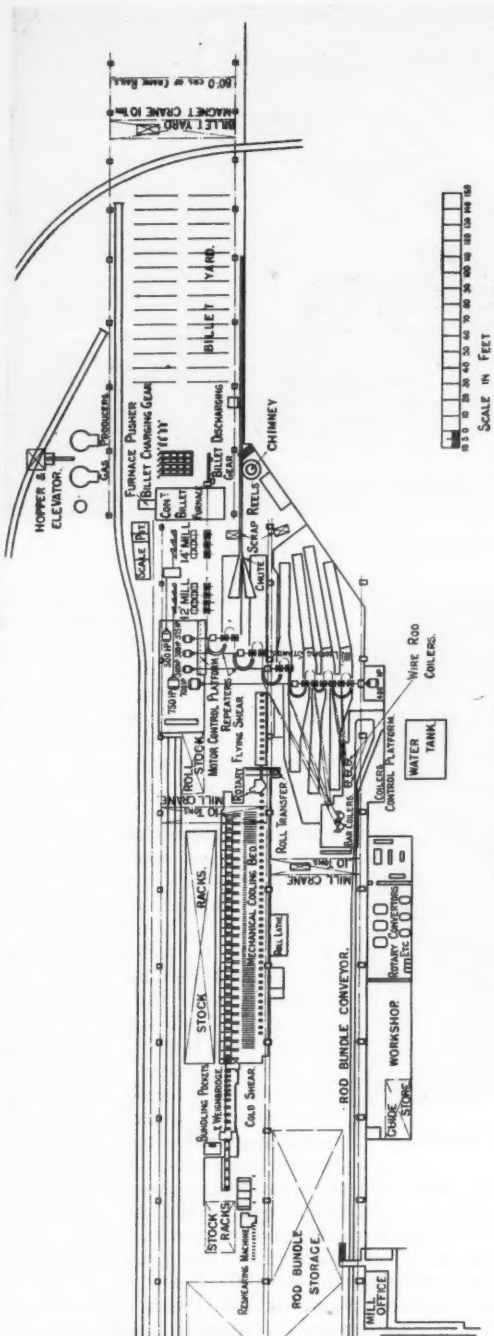


Fig. 1—Layout of mill

gas from a static producer plant. Two producer units are installed, one operating and one standby. The fuel is discharged from wagons into a ground hopper and lifted by bucket elevator to bunkers located above the producers. Steam for blowing the producers is generated in an independent firetube boiler.

The heated billet is ejected from the furnace by means of a peel-type pusher, passes through a scale-breaking unit, and enters the first stand of the continuous roughing mill, the rolls of the successive stands of which are progressively speeded up for passing the increasing length of the bar. A pendulum-type cropping and dividing shear is installed between the furnace and stand 1, but is used only in cases of emergency. On leaving stand 7 the rolled billet is automatically looped into stand 8, and, on emerging, is caught and entered by hand into stand 9, this being the first time the steel is operated manually after leaving the furnace. On leaving stand 9 the piece is automatically repeated into stand 10 and again caught by a second catcher, who enters it into stand 11 for discharge on to the cooling bed, if it is not less than $\frac{5}{16}$ in. in dia., or on to the reels if of smaller size, which necessitates extending the series of operations still further along the mill. The last stand of the mill delivers the smallest size which the mill is required to produce, that is, rods of 5 gauge for subsequent drawing into wire. A view of the mill as set up for the rolling of bars in straight lengths, showing

Table I

DETAILS OF ROLL STANDS AND DRIVES

Stand No.	Roll Diameter, in.	Motor		Rolled Sizes
		h.p.	r.p.m.	
1	15	500	110/300	
2	$14\frac{3}{4}$			
3	$14\frac{1}{4}$			
4	$13\frac{3}{8}$	750	100/250	
5	13			
6	$12\frac{5}{8}$			
7	$12\frac{1}{4}$			
8	$10\frac{3}{4}$	375	140/350	
9	$11\frac{7}{8}$			
10	$10\frac{3}{4}$	300	150/350	$\frac{7}{16}$–$1\frac{1}{4}$ in. dia.
11	$11\frac{1}{2}$			
12	$10\frac{3}{4}$	300	270/300	$\frac{5}{16}$–$\frac{3}{8}$ in. dia.
13	$11\frac{1}{2}$			
14	$10\frac{1}{4}$	700	250/600	2 S.W.G.
15	$11\frac{1}{2}$			
16	$11\frac{5}{8}$			$\frac{1}{4}$ in. dia.
17	13			
18	11	400	250/600	5 S.W.G.
19	12			

the reheating furnace, the continuous roughing mill, and stands 8–11 of the intermediate and finishing mills is reproduced in Fig. 2.

Small sizes, when rolled for straight lengths, are much longer than could be reasonably accommodated on the cooling bed, and an automatic shear is therefore installed between the mill and the cooling bed to cut the bar into suitable lengths. This shear is of the rotary-blade type in which two circular discs are located one above the other, and inclined at an angle to the direction of travel of the bar. These blades overlap slightly and rotate in opposite directions at the same speed. To effect a cut, the bar is moved across the point of engagement of the two discs by means of a guide channel. Immediately the cut has taken place, the bottom disc is lowered to create a gap and the end of the bar is moved backwards to its original position by means of the guide trough. Further cuts are effected by a repetition of this motion. The cooling bed, which is 150 ft. long, is of the reciprocating-rake type, and is provided with lift-over gear for transferring the bar from the runout table behind the shear to the rakes, and assembly and carry-over gear for transferring the cooled bars to the shears-approach roller table. A view of the rotary flying shear and mechanical cooling bed, as seen from the mill, is shown in Fig. 3.

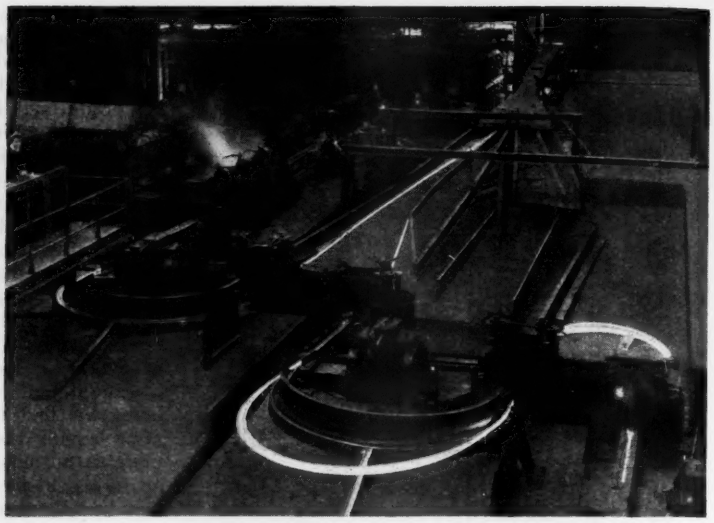


Fig. 2—Roll Stands for bars

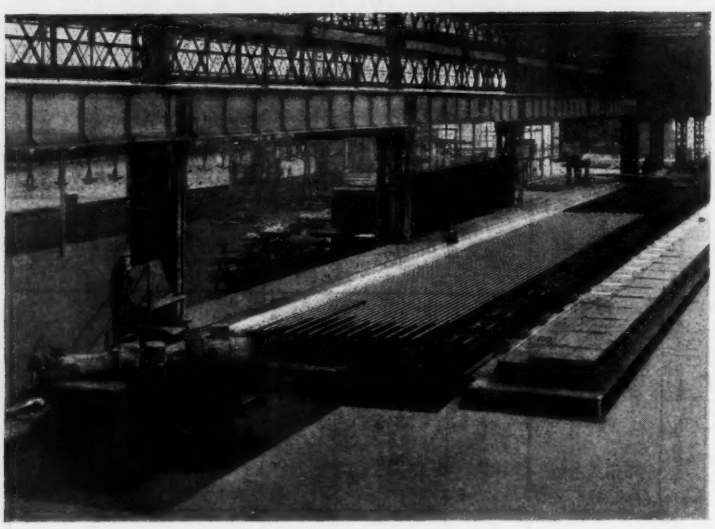


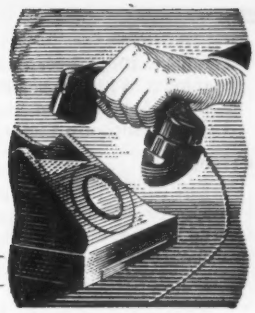
Fig. 3—Mechanical cooling bank with rotary flying shears

The operations of hot-shearing, conveying on to the cooling bed, and transferring across the cooling bed are entirely automatic, the mechanism being set in motion by the front end of the rolled bar making contact with a flag-type master switch. The cold bars are cut to final length on an electrically driven bar shear and collected in bundling pockets arranged behind the shear and mounted on a weighbridge. Another cold-bar shear is installed in the same building for re-shearing purposes.

In this plant mechanical and electrical details have received special consideration, and many novel features are incorporated. All bearings and gears are automatically lubricated, and particular attention has been paid to the design of roll-neck bearings to ensure minimum power consumption and the maintenance of gauge without the necessity for frequent roll setting. The bearings on the continuous roughing mill are white-metal-lined, with forced-feed grease lubrication; on the remaining roll stands fabric-type bearings are used. Roller bearings have been extensively adopted for the auxiliary machinery, and all conveying rollers are operated by direct-coupled fractional-horse-power motors, which eliminate intermediate gear. Being required to work under conditions of great flexibility, the main mill drives have been sub-divided in such a manner as to allow of wide relative variations in speed between the different groups of roll stands, the speeds of which can be instantaneously adjusted by a single operator who is stationed at an elevated control desk with a clear view of all rolling operations.

The mill is provided with all the usual services, such as roll-turning, guide preparation, and maintenance facilities, and with the exception of major repairs, functions as a completely independent unit.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Symposium on Peeling

A meeting to discuss peeling of whiteheart malleable cast iron and the penetration of sulphide in the carburization of steel will be held at the offices of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday, 8th April, 1948, at 2.0 P.M. Mr. J. G. Pearce, Director of the British Cast Iron Research Association, will be in the Chair. A buffet luncheon (price 6*s.* per ticket) will be served in the Institute's offices at 1.0 P.M., before the meeting.

The following are the papers for discussion :

"*Symposium on the Peeling of Whiteheart Malleable Cast Iron*" (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Jan., pp. 1–36), comprising the following papers :

"*Introduction*," by J. C. W. Humfrey.

"*The Formation of Peel on Whiteheart Malleable Cast Iron*," by A. Preece and K. J. Irvine.

"*Peel on Whiteheart Malleable Cast Iron*," by J. S. Bowden.

"*Peeling of Whiteheart Malleable Iron*," by G. R. Webster and A. E. Probst.

"*Experimental Work Carried out at the British Cast Iron Research Association*," by J. Bernstein.

"*Sulphide Penetration in the Carburization of Steel*," by A. Preece and K. J. Irvine (*Journal of The Iron and Steel Institute*, 1947, vol. 157, Nov., pp. 336–343).

Members of the Institute of British Foundrymen and of the staffs of member-firms of the British Cast Iron Research Association are cordially invited to attend the meeting and to join in the discussion. Persons who are not members of The Iron and Steel Institute can obtain copies of the papers and a ticket for the buffet luncheon by sending their application accompanied by a remittance for 10*s.* to the Secretary of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1.

Indian Institute of Metals

Inaugural Meeting

The inaugural meeting of the Indian Institute of Metals was held on Monday, 29th December, 1947, at the Royal Asiatic Society's Hall, Park Street, Calcutta. After a welcome to those present by the President of the Organizational Council, Sir Jehangir Ghandy, C.I.E., took the Chair and requested Dr. Syama Prasad Mookerjee, Minister for Industry and Supply, to inaugurate the Institute. Sir Jehangir Ghandy then delivered his Presidential address, and the meeting closed with a vote of thanks proposed by Dr. Malhotra to the Minister and the President.

Summaries of the speeches will be given in the next issue of the *Journal*.

Collaboration

An offer made by the Council of The Iron and Steel Institute for collaboration with the Indian Institute of Metals has been accepted. An arrangement has been made whereby members of the Indian Institute will be entitled to become members of The Iron and Steel Institute at the following reduced fees :

Members—£2 12*s.* 6*d.* a year instead of £3 3*s.* 0*d.* (entrance fee £2 2*s.* 0*d.*).

Associates—£1 1*s.* 0*d.* a year instead of £1 5*s.* 0*d.* (no entrance fee).

Symposium on Blast-Furnace Practice

Provisional arrangements have been made to hold a Symposium on Blast-Furnace Practice, on Wednesday and Thursday, 26th and 27th May, 1948. Further particulars will be announced in a future issue of the *Journal*.

EDUCATION

National Certificates in Metallurgy

Pass Lists

ORDINARY CERTIFICATE

The following candidates successfully completed the senior part-time course for the year 1946–47, and have been awarded the Ordinary National Certificate in Metallurgy. This list is supplementary to that published in the January, 1948, issue of the *Journal*.

Smethwick, The Chance Technical College—Garratt, Harold Joseph ; Greensmith, Joseph Frederick ; Hayward, Brian Philip ; Moore, Harold ; Peyton, Benjamin Alfred ; Weavers, Alan Albert ; Woodward, Richard Rudolph ; Yarnell, Raymond Charles (distinction awarded in chemistry) ; York, Arthur John.

HIGHER CERTIFICATE

The following candidates successfully completed the advanced part-time course for the Higher National Certificate in Metallurgy ; no distinction was awarded.

Wednesbury, County Technical College — Beebe, Trevor ; Bickley, Alan Geoffrey ; Burkin, Derek ; Cattell, Dorothy May ; Dugard, Stanley Edward ; Hartill, Albert E. ; Holloway, John Douglas ; Kitson, Harold Edward ; Lloyd, Rex ; London, Derek Wilfred ; Mercer, Geoffrey Henry Ernest ; Morgan, Edward Llewellyn ; O'Connor, Denis ; Parton, John

Thomas; Phipps, Kenneth James; Vaughan, Charles Stanley; Whitehouse, Richard William.

Wolverhampton and Staffordshire Technical College—Tansley, Anthony Victor.

Prizes

Prizes (to be taken in books) will be awarded to the following candidates in respect of the Final Examinations for the Ordinary and Higher National Certificates held in June 1947:

ORDINARY CERTIFICATE

Battersea Polytechnic, London—Graham, John Alastair (one guinea); James, Victor Leonard (four guineas).

Birmingham Central Technical College—Burnard, David Chance (one guinea).

Chesterfield Technical College—Moss, John Barry (two guineas).

Rotherham Technical College—Broadbent, Peter Robert (one guinea).

Smethwick, The Chance Technical College—Allen, Gordon Leonard (one guinea); Dunning, Malcolm John (three guineas); Forsyth, Richard Victor Walter (two guineas); Harris, Leslie Howard William (one guinea); McManus, William George (three guineas); Salmon, Clifford Gerald (one guinea); Scott, John Edward (four guineas); White, John Harold (four guineas).

Swansea Technical College—Rees, George Philip (one guinea).

Wednesbury, County Technical College—Richards, Charles John Godfrey (one guinea); Wakeman, Peter John (one guinea).

Wolverhampton and Staffordshire Technical College—Meachem, Frederick Arthur (three guineas).

HIGHER CERTIFICATE

Wednesbury, County Technical College—Bickley, Alan Geoffrey (one guinea).

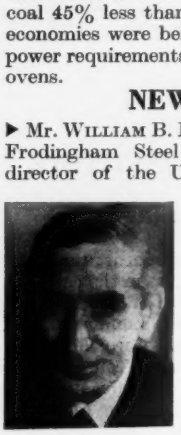
Seventy-Five Years Ago

It is often said that history repeats itself. Although this may not be as true in the technical field as in the political world, it is evident from the Presidential address to the Institute, in 1873, that something in the nature of a crisis was imminent in the iron and steel industry owing to the rapidly increasing price of coal. Mr. (later Sir) Lowthian Bell, in his address, said that the industry declined rapidly when timber became scarce and it was possible that a similar decline would now occur, although this would in turn release large quantities of coal and so reduce prices. There was no doubt, however, continued the President, that the iron industry would extend greatly and make further demands on the collieries. He thought the additional fuel would be obtained but, he said, "it is very possible that the time is approaching when any extension of manufacturing operations in this country will have to be regulated, not by the requirements of society for their produce, but by the means our coal mines possess of furnishing the fuel required."

The iron and steel industry at this time was using about 30% of the total production of coal; as much as the next two largest consumers together. Opinion had already been expressed that the industry was using coal very much in excess of its needs, and Sir Lowthian Bell attempted to answer this charge by explaining how the ironmaster was endeavouring to cut down fuel consumption. Starting with the blast-furnace, he referred to Neilson's introduction of the hot blast about 40 years ago, which increased the make of the furnace four times and reduced the fuel consumption by 50%. Some 10 or 15 years previously experiments had been made, in the North of England, by increasing the height of furnaces, to such an effect that savings of fuel up to 35% of that previously consumed were obtained, and the make was increased to 400 tons per week. The President concluded his argument with the statement that Cleveland blast-furnaces were making pig iron with a consumption of coal 45% less than in 1860. At the same time further economies were being made in utilizing waste gases for power requirements, particularly the gases from the coke ovens.

NEWS OF MEMBERS

▶ Mr. WILLIAM B. BAXTER, general manager of Appleby-Frodingham Steel Company, has been appointed a director of the United Steel Companies, Ltd. He



was trained as an engineer and first became associated with the steel industry in 1914. At that time he joined the Frodingham Iron and Steel Company, now the Appleby-Frodingham Steel Company, and after assisting the late Mr. James Henderson became works manager in 1927 and general manager in 1939. As from 1st January, 1948, he has acted as joint general manager.

He is a Vice-President of The Iron and Steel Institute, and a Member of Council of the British Iron and Steel Research Association and Chairman of the Plant Engineering Division. Mr. Baxter is also Chairman of the Lincolnshire Ironmasters' Association.

▶ Mr. R. BARNES has now left the Skinningrove Iron Co., Ltd., Saltburn-by-the-Sea. His new address is c/o South Durham Steel and Iron Co., Ltd., Cargo Fleet Iron Works, Middlesbrough.

▶ Mr. QUINCEY BENT has retired from his position of Vice-President in charge of steel-division operations of the Bethlehem Steel Corporation, but will continue to serve in an advisory capacity.

▶ Mr. W. R. BERRY has recently resigned from the Board of Messrs. Ibbotson Brothers, Ltd., Sheffield, and from his appointment as chief development engineer to the Woodhead Group of Companies, and has commenced a practice as a consulting engineer and metallurgist. His address is Grey Garth, Wynmore Avenue, Bramhope, near Leeds.

▶ The United Steel Companies, Ltd., announce that the following appointments have been made at the Appleby-Frodingham branch: As from 1st January, 1948, Lt.-Cdr. G. W. WELLS becomes joint general manager with Mr. W. B. BAXTER. Mr. A. ROBINSON becomes technical consultant and joins the Board of the Appleby-Frodingham branch. Eng. Rear-Admiral C. W. LAMBERT becomes general works manager, and Mr. A. JACKSON, Mr. G. D. ELLIOT, and Mr. W. GEARY are appointed works managers. Mr. J. L. GASKELL is appointed chief electrical engineer.

▶ Mr. H. BOOTMAN has taken up a position as metallurgist in charge of refining and moulding, with Messrs. H. J. Enthoven and Sons, Ltd., Matlock.

▶ Mr. S. H. BROOKS has resigned his post as fuel engineer at Messrs. Stewarts and Lloyds, Ltd., Corby, and will shortly be taking up an appointment with the United Steel Companies, Ltd., Department of Research and Technical Development, as assistant to Mr. F. A. Gray, Head of the Fuel Section.

▶ Mr. WILLIAM BARKER BROOKS, previously with the Alloys Development Company, is now a consulting

metallurgist at 615, Park Building, Pittsburgh, Pennsylvania, U.S.A.

▶ Mr. A. F. DIXON has retired from his position as chief engineer of the Brightside Foundry and Engineering Co., Ltd., Sheffield, but will continue to serve the company as a consultant.

▶ Mr. P. N. GANDHI has changed his address to Metallurgy Department, Tata Iron and Steel Co., Ltd., Jamshedpur, India.

▶ Mr. P. K. GLEDHILL is now at the Chemical Laboratories, Messrs. Stewarts and Lloyds, Ltd., Corby.

▶ Mr. B. M. HARDMAN has recently been released from H.M. Forces and has been appointed lecturer in metallurgy at the North Staffordshire Technical College, Stoke-on-Trent.

▶ Mr. E. D. HARRY has resigned his post as metallurgist with the Workington Iron and Steel Co., Ltd., and has now taken up an appointment as a metallurgist with the Steel Company of Wales, Ltd., at Newport, Mon.

▶ Mr. J. E. MILLER has taken up the position of London Manager of the Chesterfield Tube Co., Ltd., with offices at The Adelphi, Strand, London, W.C.2.

▶ Mr. FRED MILLS, recently resident engineer to the Steel Company of Wales, Ltd., has retired after 44 years' association with the iron and steel industry. He served his apprenticeship with Messrs. Baldwins, Ltd., beginning in 1904, and was chief engineer from 1914 until 1944. During this period he was responsible for the layout of the Margam iron and steel works, giving particular attention to the design and erection of the steelworks section, and new plant at Gowerton, Wildon, and Panteg.

In 1927 he assisted in the design and erection of the Elba tinplate works at Swansea, where he served as works manager and engineer. Subsequently he was group development engineer for the planning of post-war modernization of steel and tinplate works. Mr. Mills, who joined The Iron and Steel Institute in 1919, has made a number of visits to the Continent and to the U.S.A.

▶ Dr. E. OROWAN, F.R.S., is now reader in metal physics at Cambridge University.

▶ Mr. J. A. RABBITT has changed his address to c/o I.C.I. (China), Ltd., 133, Szechuen Road, Shanghai, China.

▶ Mr. S. RAMAMURTHY has resigned from his position as research metallurgist with Messrs. Jyoti, Ltd., Baroda, India. His present address is c/o S. Balakrishnan, 4, Normal School Quarters, Sitabuld, Nagpur, India.

▶ Monsieur P. ROCQUET was recently appointed Director of the Departement de Chimie et de Chimie Physique at the Institut de Recherches de la Siderurgie.

▶ Mr. E. J. D. SMITH has left the Motor Industry Research Association, and has taken up an appointment as scientific officer in the Refractories Section of the British Iron and Steel Research Association.

▶ Mr. HOWARD E. N. STONE has now left the Mond Nickel Co., Ltd., Birmingham ; he has joined the British Iron and Steel Research Association, and is stationed at the National Physical Laboratory, Teddington.

▶ Mr. H. L. TURNER, previously with Messrs. F. H. Lloyd and Co., Ltd., is now at the Bridge Foundry Co., Ltd., Wednesbury.

▶ Mr. WILLIAM UDALL has been appointed chief engineer of the Brightside Foundry and Engineering Co., Ltd., Sheffield.

▶ Mr. FRANK WALTON has changed his address to c/o Alloy Steels, Ltd., Christchurch, New Zealand.

▶ Mr. GEORGE R. WARD has taken up a position as assistant blast-furnace manager at the Cargo Fleet Iron Co., Ltd.

▶ Mr. E. J. WILLEY is now with the South Durham Steel and Iron Co., Ltd., West Hartlepool.

▶ Mr. DAVID T. WILLIAMS has left Messrs. J. Summers and Sons, Ltd., Shotton, and is studying metallurgy at Manchester University.

▶ The announcement in the December, 1947, issue of the *Journal*, concerning Mr. A. D. ROBERTSON, of the United Steel Companies, Ltd., was incorrect, and apologies are made to him for any inconvenience which that notice may have caused.

Elections

▶ Mr. BASIL W. DONCASTER has been elected President of the Sheffield Society of Engineers and Metallurgists.

▶ Lieut.-Col. Sir JOHN GREENLY, K.C.M.G., C.B.E., an Honorary Vice-President of The Iron and Steel Institute, has been elected a Fellow of the Institute of Metals.

▶ Mr. NEVILLE H. ROLLASON, Member of Council of The Iron and Steel Institute, has been appointed President-Elect of the British Iron and Steel Federation.

Awards

▶ Dr. U. R. EVANS has been awarded the degree of D.Sc., *honoris causa*, of Dublin University.

▶ Mr. EUGENE GIFFORD GRACE, Chairman of the Board of Bethlehem Steel Corporation, has been awarded the Charles F. Rand Gold Medal of the American Institute of Mining and Metallurgical Engineers.

Memoranda

▶ The address of the Department of Development and Research of Tube Investments, Ltd., is now Plume Street, Aston, Birmingham, 6.

▶ Messrs. Stein and Atkinson, Ltd., have now moved their Head Office to Parnell House, 25, Wilton Road London, S.W.1.

Obituary

The Council regret to record the deaths of :

Mr. JOHN CHRISTOPHER CLIFTON, late of Vickers Armstrongs, Ltd., on 29th December, 1947.

Lt.-Col. ARTHUR HIBBERT, on 19th December, 1947.

Mr. F. NEPPER, on 28th July, 1947.

Mr. R. WATSON, General Manager, Scottish Group of Tube and Steel Works, Stewarts and Lloyds, Clyde Works, Coatbridge, on 27th November, 1947.

Mr. G. WILLIAMS, of Messrs. Harold Andrews Grinding Co., Ltd., Birmingham, on 3rd December, 1947.

CONTRIBUTORS TO THE JOURNAL

R. Hill, M.A. (Cantab.)—Engaged in research on theoretical plasticity, at Cavendish Laboratory, Cambridge. Mr. Hill was born in 1921 and educated at Leeds Grammar School and at Pembroke College, Cambridge, where he was awarded in 1942 the degree of B.A., and the M.A. in 1945. From 1941 to 1943 he worked under Professor J. E. Leonard-Jones in the Mathematics Laboratory, Cambridge, on the theory of internal and external ballistics. In May 1943 he joined the Armament Research Department at Fort Halstead, Kent, working under Professor N. F. Mott, F.R.S., on theoretical problems connected with armament research. Mr. Hill began research in the Cavendish Laboratory, under Dr. E. Orowan, F.R.S., in April 1946.

K. A. Pyefinch, M.A.—A member of The Iron and Steel Institute team of workers since 1942 on problems of

E. Bishop

J. E. O. Mayne

R. S. Thornhill

L. Northcott

fouling and, from 1944, biologist to the Marine Corrosion Sub-Committee. Mr. Pyefinch was formerly lecturer in zoology at University College, Nottingham.

J. E. O. Mayne, Ph.D., F.R.I.C., A.R.C.S., D.I.C.—University Chemical Laboratory, Cambridge. Dr. Mayne graduated at the Royal College of Science in 1929. He then worked for a year on inorganic chemistry in the research laboratory of the late Professor H. B. Baker, and subsequently was appointed to the position of research chemist in the wire-rope section of the Safety in Mines Research Board. In 1938 he went to Cambridge to work in the laboratory of Dr. U. R. Evans, and later obtained a part-time post there. Dr. Mayne was one of the founders of Vinyl Products, Ltd., in 1939.

L. Northcott, D.Sc.—Superintendent of Metallurgical Research, Armament Research Department, Woolwich. Educated at the University of Birmingham, Dr. Northcott joined the metallurgical branch of the Research Department, Woolwich, in 1924. In December 1940 he was evacuated to the National Physical Laboratory where he remained until his return to Woolwich in March 1947. He was appointed to his present position, as successor to Dr. R. H. Greaves, in the following August.

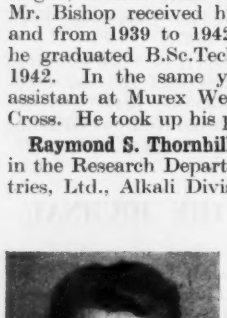
Edward Bishop, B.Sc.Tech.—Research Welding Metallurgist, Messrs. Wm. Jessop and Sons, Ltd., Sheffield. Mr. Bishop received his early education at Barnsley, and from 1939 to 1942 at Sheffield University, where he graduated B.Sc.Tech. (Hons. Glass Technology) in 1942. In the same year he was appointed research assistant at Murex Welding Processes, Ltd., Waltham Cross. He took up his present post in 1947.

Raymond S. Thornhill, M.A., Ph.D.—Technical officer in the Research Department, Imperial Chemical Industries, Ltd., Alkali Division, Northwich. Dr. Thornhill was educated at the Grammar School, Burton-on-Trent, and at the University of Cambridge, where he received his B.A. degree in 1932. In the same year he went to the Imperial College of Science and Technology to carry out research on electrochemical problems, returning in 1935 to Cambridge to the Corrosion Section, under Dr. U. R. Evans, where he remained, apart from a year in the paint industry, until 1944.

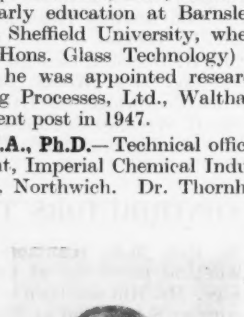
W. Murray, A.M.C.T., F.R.I.C.—Water-Treatment Consultant with Feedwater Specialists Section of Liverpool Borax Co., Ltd. Mr. Murray was educated at Wigan Mining College, and at the College of Technology, Manchester. His early industrial experience was concerned with terra-cotta and coal carbonization, and this was followed by a period in the research department of I.C.I. (Alkali), Ltd. Mr. Murray is the author or co-author of a number of papers.

K. Hoselitz, Ph.D., F.Inst.P.—Director of Research, Permanent Magnet Association, Sheffield. Dr. Hoselitz was born in Vienna in 1916. In 1934 he entered the University of Vienna, and after three years of study he started work on a thesis on the investigation of the structure of polymers by means of electron diffraction, under the direction of Professor H. Mark. The German invasion of 1938 forced Dr. Hoselitz to interrupt his work and, having come to this country, he was accepted as a research student at the University of Bristol, where he continued to work for his doctorate under the direction of Professor A. M. Tyndall, F.R.S. In 1940 he began a study under Professor W. Sucksmith, F.R.S., on iron-nickel alloys and in 1941 was awarded the degree of Ph.D. of the University of Bristol.

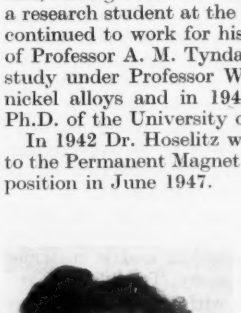
In 1942 Dr. Hoselitz was appointed research scientist to the Permanent Magnet Association, and to his present position in June 1947.



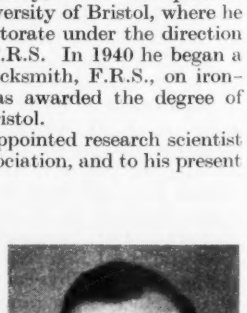
W. Murray



H. Heitler



K. Hoselitz



K. M. Guggenheimer

E. C. Rollason

R. S. Sharpe

W. Betteridge

K. M. Guggenheimer, Ph.D.—I.C.I. Research Fellow in the Department of Natural Philosophy, University of Glasgow. Dr. Guggenheimer was born in Munich in 1902 and educated at the University of Munich from 1921 to 1927. On leaving the University he took up research work at the Kaiser Wilhelm Institut (1927–33), at the College de France, Paris (1933–35), and in Munich (1935–39). In 1939 he came to this country and became a research student at King's College, Cambridge, where he remained until 1943, when he left to take up a lectureship and to continue research work at the University of Bristol. He has held his present position since July 1947.

H. Heitler, Ph.D., was born at Karlsruhe, Germany, in 1899. He graduated in 1923 at the Technische Hochschule, Karlsruhe, in mechanical engineering, and in 1926 in the Special State examination. From 1927 to 1928 he was a consulting engineer in heat and power economics in textile, leather, paper, timber, and similar industries. In 1939 Dr. Heitler emigrated to England and took up research work at the H. H. Wills Physical Laboratory, University of Bristol, where he was awarded the degree of Ph.D. in 1947. The main subjects of his research have included the magnetic properties of ferromagnetic materials, and nuclear physics.

R. Mayorcas, B.Sc.—Head of the Heat and Thermodynamics Section, Physics Laboratories, British Iron and Steel Research Association. Mr. Mayorcas was born in London in 1920, and educated at Chiswick County School and at Birkbeck College, London University, graduating in 1944. From 1938 to 1945 he was engaged upon research for the British Coal Utilisation Research Association, where he was concerned with work on producer-gas machines, the down-jet method of combustion, and the use of radon for aerodynamic studies of hot gases. He was associated with Dr. Chesters and Mr. Thring in their work on the influence of port design on open-hearth furnace flames.

Mr. Mayorcas took up his present position with B.I.S.R.A. in 1945.

M. Diana Hedgcock, B.Sc.—Physicist at the British Iron and Steel Research Association. Miss Hedgcock was born and educated in London, and in 1946 obtained the B.Sc. degree of London University in mathematics and physics. She is now with the Heat and Thermodynamics Section of the Physics Department of the British Iron and Steel Research Association.

Dr. E. C. Rollason—Delegate Director and Research Manager of Murex Welding Processes, Ltd. Dr. Rollason was educated at Dudley Grammar School, at Dudley Technical College, where he obtained a National Certificate in Engineering, and at Birmingham University, where he was awarded the degree of B.Sc. in 1930, followed by the M.Sc. in 1932, and the Ph.D. in 1939. He has held posts as lecturer at the County Technical College, Wednesbury, as senior lecturer in metallurgy at Birmingham University, and as examiner for several educational bodies.

He joined his present firm in 1940 to undertake welding research, and was appointed research manager in 1942; a year later he was given a seat on the Delegate Board.

From 1935 to 1945 Dr. Rollason was Honorary Secretary and Editor to the Staffordshire Iron and Steel Institute. He is the author of the textbook "*Metallurgy for Engineers.*"

W. Betteridge, Ph.D.—Research Metallurgist, Development and Research Department, the Mond Nickel Co., Ltd. Born in 1911, Dr. Betteridge was educated at King Edward's School, Birmingham, and at Birmingham University, where he graduated in the Honours School of Physics in 1931. He was awarded a Richard Fenwick Post-Graduate Scholarship, and obtained the degree of Ph.D. in 1933. From 1933 to 1936 he worked with Messrs. Joseph Lucas, Ltd., on permanent-magnet alloys and electrical contacts, and in 1936 left to take up a position as assistant chief metallurgist of the Aero-Engine Division of the Bristol Aeroplane Co., Ltd. For some years he was a Committee member and Vice-President of the Industrial Radiology Group of the Institute of Physics. Dr. Betteridge left Bristol in June of this year to join the Mond Nickel Co., Ltd.

Roy S. Sharpe, B.Sc.—Physicist at the Aero-Engine Division Laboratories of the Bristol Aeroplane Co., Ltd. Mr. Sharpe received his early education at Hove and at Reading University where he graduated with honours in a general science degree. On leaving Reading he took up his present position at Bristol, and during the last three years has specialized under Dr. W. Betteridge on X-ray metallography.

IRON AND STEEL ENGINEERS GROUP

Provincial Meeting

Leeds

A joint meeting of the Iron and Steel Engineers Group and the Leeds Metallurgical Society will be held on 4th March, 1948, at the Chemistry Department, Leeds University, at 7 P.M. Dr. A. T. Bowden (C. A. Parsons and Co., Ltd.) will present a paper on "*Gas Turbine Applications in Iron and Steel Works*" (published in the May, 1947, issue of the *Journal*).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Metal-Flow Research Laboratory

As from 1st January, 1948, certain sections of the Mechanical Working Division of the British Iron and Steel Research Association will be housed in temporary premises at 41, Doncaster Street, Sheffield. The administration will be in the charge of Mr. C. N. Kington.

The Rolling-Mill Section has not been transferred to the new premises, but remains at the Applied Science Department, Sheffield University.

Factors in the Screening of Iron Ores

Report No. IM/A/32/47 of the Burden Committee of the Ironmaking Division of the British Iron and Steel Research Association, describes the factors involved in the screening of iron ores. This process is an important part of the preparation of a suitable burden for the blast-furnace, and the provision of quite extensive screening facilities has yielded increasingly valuable results, particularly with the development of larger furnaces and faster rates of driving, although some large plants continue to operate on totally unscreened ores. In addition to improving the output and nature of the product from the crushing machines, adequate screening of ores is essential for smooth and rapid operation in the blast-furnace.

Iron-Ore Treatment and Blast-Furnace Practice in the U.S.A.

Report No. IM/A/31/47 issued by the Burden Committee of the Ironmaking Division of the British Iron and Steel Research Association, comprises a few generalized impressions formed during the course of an extensive tour of a number of blast-furnace plants and ore-mining centres in the U.S.A. Three main aspects are considered: Ore concentration, agglomeration of fines, and modification of the technique of blast-furnace operation.

AFFILIATED LOCAL SOCIETIES

Ebbw Vale Metallurgical Society

As announced in last month's issue of the *Journal*, the Ebbw Vale Metallurgical Society became affiliated to The Iron and Steel Institute as from 1st January, 1948. The List of Officers of the Society for the 1947–48 Session is as follows:

Chairman

E. HEMINGWAY-JONES, A.M.I.Chem.E., M.Inst.F.

Vice-Chairman

H. F. PADBURY, A.I.M.

Hon. Treasurer

R. C. POWELL, B.Sc.

Members of Committee

W. H. R. BIRD, M.A., B.Sc.
T. COOK
H. EVANS
D. W. GEORGE
A. H. GREY
W. D. JENKINS, B.Sc.
M. JONES
T. JONES, A.C.I.S.
G. W. LEWIS
F. LLEWELLYN
H. NEAL
F. E. PROBYN
W. J. S. ROBERTS, B.Sc., F.I.M.
S. F. SMITH
O. SMITH, A.L.A.A.
H. STEELE

Hon. Joint Secretaries

F. W. LEWIS and E. G. BRACE

THE INSTITUTE OF METALS

Annual General Meeting

The Annual General Meeting of the Institute of Metals will be held on Tuesday, Wednesday, and Thursday, 16th–18th March, 1948, at the Institution of Civil Engineers, Great George Street, London, S.W.1. Sir Arthur Smout, J.P., will take office as the new President. The meeting will commence on the afternoon of Tuesday, 16th March, when the Reports of Council and of the Honorary Treasurer will be presented, and the new President will deliver his address.

NEWS OF SCIENCE AND INDUSTRY

Fourth Plenary World Power Conference

The International Executive Council of the World Power Conference unanimously accepted, at its recent Meeting at The Hague, an invitation from the British National Committee for the Fourth Plenary World Power Conference to be held in London, in 1950. In the regrettable absence, owing to an indisposition, of Sir Harold Hartley, K.C.V.O., C.B.E., F.R.S., Chairman of the British National Committee, this invitation was conveyed to the Council by Mr. Harold Hobson, in his capacity as Vice-Chairman. Mr. Hobson was able to inform the Council that the British Government had promised their full support.

Abstracts

A limited quantity of reprints of the Abstract Section printed on one side only is available. Copies from January 1948, can be obtained at a cost of £2 per annum on application to the Secretary.

Mechanical Handling Exhibition

The First Mechanical Handling Exhibition and Convention, organized by the journal *Mechanical Handling*, is to be held in the National Hall, Olympia, London, W.14. from Monday, 12th July, to Wednesday, 21st July, 1948. All enquiries for stand sites should be addressed to Mr. H. A. F. Collman, Advertisement Manager of *Mechanical Handling*, who will act as Space Manager. The Convention, organized and convened by Mr. P. J. Joynes, Editor of *Mechanical Handling*, will be planned to be of practical value to visiting industrial buyers and will demonstrate the technique of mechanical-handling methods as applied to production. The Convention will be addressed by technical experts who will present the case for mechanical handling from the manufacturers' and the users' points of view.

Industrial and Commercial Education

WORKING PARTY'S REPORT

The report of the working party set up in September last by Mr. George Tomlinson, Minister of Education, to report on the establishment of a National Council of Technology, has been published recently.

The working party recommend that steps should be taken to establish a National Council on Education for Industry and Commerce to advise the Minister on the national policy for the full development of education in this sphere, stating: "At this time, as never before, there is a real need for well-trained craftsmen, technicians, technologists, scientists, research workers, and managers.

Such training calls for careful and concerted planning and it is evident that a national body is needed to give informed advice in order that development may proceed along sound lines."

International Geological Congress

The Eighteenth Session of the International Geological Congress will be held in London from 25th August to 1st September, 1948, on the invitation of the Geological Society of London. The Headquarters and Office of the Session are in the building of the Geological Survey and Museum, Exhibition Road, South Kensington, London, S.W.7, and Members wishing to have further information should get in touch with the General Secretaries at that address.

Verein Deutscher Eisenhüttenleute

The first meeting of the Verein Deutscher Eisenhüttenleute after the collapse of Germany was held on Friday, 26th September, 1947, in the Europa Palast Theatre, Düsseldorf, and was attended by some 2000 members. The Secretary, Dipl. Ing. K. P. Harten, reported upon the activities of the Verein in the reconstruction of its internal organization and the iron and steel industry as a whole, mentioning that over 95% of the former members, in all four zones, had been registered again. Five short papers were read, all of which were concerned with some aspect of the many shortages—high-grade ore, coal, alloy steel, and manpower—which are handicapping the industry.

In his final address the Chairman, Dr. Ing. E. Herzog, discussed the wider problems of transport and the structure of the industry and emphasized that the crux of the task of reconstruction was labour and food.

Australian School of Mines Ceramics Laboratory

The South Australian Government is establishing a ceramics laboratory at the School of Mines. The Government will finance research over the next five years to test the suitability of various clays for the production of ceramics. The State has large reserves of clay of kinds which it is believed are suitable for ceramic ware, but they are not being exploited by existing potteries. It is hoped that a more thorough investigation of the raw materials available will lead to extension of both the range and the quality of production. The Council for Scientific and Industrial Research has obtained the services of a specialist from Britain to take charge of the investigation.

Production of Tinplate in Australia

The Broken Hill Pty. Co., Ltd., is making investigations in preparation for the establishment of tinplate and other special steel-sheet production in Australia. It is expected that the Australian tinplate industry will be launched at Port Kembla.

British American Research, Limited

The formation is announced of British American Research, Limited, which has recently been incorporated in Scotland as a joint venture with Messrs. Daniel Varney, Ltd. British American Research, Limited, will undertake the manufacture and sale of the industrial high-vacuum equipment which was developed by the National Research Corporation and used in such fields as high-vacuum evaporation, distillation, dehydration, and metallurgy. This new British company will not only facilitate the availability of high-vacuum equipment, particularly to the British Empire, but, in addition, its staff will serve in a liaison capacity for the latest technical developments between the U.S.A. and Great Britain and the Continent.

The officers of British American Research, Limited, include Mr. Norman Duthie (Chairman), Dr. Charles G. Hatay (Managing Director), and Mr. Richard S. Morse and the Earl of Selkirk (Directors).

Fire Protection Association

On 17th December, 1946, Sir Edward Appleton, F.R.S., Secretary of the Department of Scientific and Industrial Research, announced the formation of the Fire Protection Association. All those who have any fire-protection or fire-prevention problems are invited to approach the F.P.A., which gives information without charge. A monthly bulletin will be issued and circulated to associate members who will also receive annual reports and the recommendations of the technical committees. Applications for associate membership of this Association are now invited, and should be addressed to the Fire Offices' Committee, Fire Protection Association, The Testing Station, Boreham Wood, Elstree, Herts.

British Oxygen Company's Welding Prize

The Council of the British Welding Research Association have gratefully accepted an offer from the British Oxygen Co., Ltd., to provide a prize fund of £100 per annum for three years for a competition relating to welding. A single prize of £100 is offered in 1948 and will be awarded for the best paper submitted on a research into welding or its application. Papers will require to be submitted on or before 30th September, 1948. Full particulars of the competition will be announced shortly.

New Blast-Furnace at Clyde Iron Works

The new blast-furnace at the Clyde Iron Works of Messrs. Colvilles, Ltd., was blown-in on Monday, 12th January, four months after its completion. The furnace has been designed for a production of 4500 tons of pig iron per week.

Mond Nickel Fellowships Committee

The Mond Nickel Fellowships Committee has decided to award two Fellowships for 1947:

To Mr. L. H. Walker (Reynolds Tube Co., Ltd.) for the study of methods of application of group industrial research, particularly in relation to the fabrication of light metals.

To Mr. D. R. G. Davies (Richard Thomas and Baldwins, Ltd.) for the study of the application of statistical methods to plant metallurgical and management methods, with particular reference to the steel industry.

Full particulars of the scheme of Mond Nickel Fellowships, which are awarded annually by The Mond Nickel Co., Ltd., will be found on page 123 of the May, 1947, issue of the *Journal*.

American Foundrymen's Association

The steel division research committee of the American Foundrymen's Association is to study the influence of mould conditions on the development of hot tears in steel castings. The research is expected to determine which factors contribute to the development of the defect and to indicate methods for the control of hot-tearing. Also involved in the project is the design of a pattern to serve as a measure of the tear-susceptibility of steel.

DIARY

21st February

SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Joint meeting with the Iron and Steel Engineers Group, The Iron and Steel Institute, "*Engineering Aspects of a Modern Steel Plant*," by W. F. Cartwright—Royal Institution of South Wales, Swansea, 6.30 P.M.

26th February

MIDLAND METALLURGICAL SOCIETIES—"*The Metallurgy of Gold, Silver, and Platinum*," by C. A. H. Jahn—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

27th February

WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Some Examples of New Measuring Instrument Techniques and their Application in the Iron and Steel Industry*," by S. S. Carlisle—39, Elmbank Crescent, Glasgow, 7.0 P.M.

1st March

CLEVELAND INSTITUTION OF ENGINEERS—"*Metallurgical Load as a Factor in Basic Open-Hearth Operation*," by A. J. Kesterton—Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, 6.30 P.M.

2nd March

SHEFFIELD METALLURGICAL ASSOCIATION—"*Early History of the Sheffield Iron and Steel Industry*," by A. Allison—198, West Street, Sheffield, 1, 7.0 P.M.

4th March

MIDLAND METALLURGICAL SOCIETIES—"*Precision Casting*," by Frank Hudson, James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

4th March

LEEDS METALLURGICAL SOCIETY—Joint meeting with the Iron and Steel Engineers Group, The Iron and Steel Institute, "*Gas Turbine Applications in Iron and Steel Works*, by A. T. Bowden—Chemistry Department, Leeds University, 7 P.M.

9th March

EBBW VALE METALLURGICAL SOCIETY—*Coal and the Future*," A. Parker—Rational Hall, Ebbw Vale, 6.45 P.M. Chairman, Mr. E. Hemingway-Jones.

15th March

SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*The Cold-Working of Metals*," by C. H. Desch, F.R.S.—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

16th March

SHEFFIELD METALLURGICAL ASSOCIATION—"*Recent Development in Non-Ferrous Metallurgy*," by A. G. Quarrell—198, West Street, Sheffield, 1, 7.0 P.M.

18th March

STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*The Manufacture of Tube Steel*," by J. McCracken—Station Hotel, Dudley, 7.0 P.M.

19th March

WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Casting-Pit Practice*," by R. Duncan—39, Elmbank Crescent, Glasgow, 6.45 P.M.

19th March

ROYAL INSTITUTION—"*Metal Physics*," by Sir Lawrence Bragg, O.B.E., F.R.S.—21, Albemarle Street, London, W.1, 9.0 P.M.

20th March

SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Some Recent Trends and Future Possibilities in Ferrous Metallurgy*," by R. A. Hacking—Royal Institution of South Wales, Swansea, 6.30 P.M.

23rd March

LINCOLNSHIRE IRON AND STEEL INSTITUTE—"*Desiliconization*," by E. F. Brown—Technical School, Cole Street, Scunthorpe, 7.30 P.M.

23rd March

SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Techniques and Results in Metallurgical Research*, by N. P. Allen—198, West Street, Sheffield, 1, 7.0 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the January, 1948, issue of the *Journal*, page 146.)

TRANSLATIONS AVAILABLE

No. 331 (German). H. BABLIK, F. GÖTZL and R. KUKACZKA: "The Structure of Hot-Galvanized Coatings." (*Korrosion und Metallschutz*, 1945, vol. 21, No. 1–2, pp. 1–8).

No. 332 (German). G. F. HÜTTIG: "The Theoretical Basis of Fritting Processes in Powders." (*Metallwirtschaft*, 1944, vol. 23, Oct. 20, pp. 367–372).

No. 333 (German). W. BAUKLOH: "Desulphurization of Iron by Hydrogen." (*Metallwirtschaft*, 1936, vol. 15, Dec. 11, pp. 1193–1196).

No. 334 (German). E. SIEBEL: "Present Knowledge of the Mechanics of Wire Drawing." (*Stahl und Eisen*, 1947, vol. 66–67, May 22, pp. 171–180).

No. 335 (Russian). F. F. VITMAN, N. N. DAVIDENKOV and N. A. ZLATIN: "Cold-Brittleness of Steel in Torsion." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, Nos. 9–10, pp. 1137–1145).

PAPER ACCEPTED FOR TRANSLATION SINCE THE LAST ANNOUNCEMENT

(German). F. EISENSTECKEN and E. H. SCHULTZ: "The Behaviour of Sulphur in the Gas and the Sulphur Balance in the Basic Open-Hearth Furnace." (*Stahl und Eisen*, 1932, vol. 52, July 14, pp. 677–686).

TRANSLATION WITHDRAWN

The translation of the paper by A. N. Tikhonov and E. G. Shoidovski entitled "Mathematical Theory of Continuous Casting" (*Journal of Technical Physics, U.S.S.R.*, 1947, vol. 17, No. 2, pp. 161–176), previously announced as in course of preparation, has been withdrawn.

CHARGES FOR COPIES OF TRANSLATIONS—For the above translations a charge will be made of 10*s.* for the first copy and 5*s.* each for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Swedish Minerals Newly Discovered. R. Knutsen. (Chimie et Industrie, 1940, vol. 44, July, pp. 81–85). A brief account is given of some minerals recently discovered in Sweden.—R. F. F.

The Mineral Resources of West Africa. G. Arnaud. (Annales des Mines et des Carburants, Mémoires, 1945, vol. 134, Nov.-Dec., pp. 639–738). This account of the mineral resources of West Africa includes particulars of the following iron ore deposits: (1) In Sierra Leone, large hematite and magnetite deposits at Tonkolili (not being worked owing to the distance from the coast) and Marampa; (2) in French Guinea, the laterite ores of Conakry; and (3) in Upper Dahomey, laterite and hematite deposits near Kandi.—J. C. R.

The Mineral Industry of Peru. J. Sanchez. (Chimie et Industrie, 1940, vol. 44, Aug., pp. 172–178). A brief account is given of the mineral resources of Peru.—R. F. F.

The Mineral Production of the Philippines. A. Struve. (Chimie et Industrie, 1942, vol. 47, Mar., pp. 454–456). The present position of the mineral industry of the Philippine Islands is described.—R. F. F.

ORES—MINING AND TREATMENT

The Laboratories of the Société Minerais et Métaux. (Echo des Mines, 1946, Dec., pp. 195–196; 1947, Jan., pp. 14–15). The new laboratories of the Société Minerais et Métaux at Paris, for the testing of ores, is described.—R. F. F.

Solving a Steel Production Problem. A. Hoffman. (Mining and Metallurgy, 1947, vol. 28, Sept., pp. 444–446). The economic situation produced in the steel industry of the United States by the shortage of steel scrap is outlined. The author proposes that the production of heavy sinter for open-hearth furnaces and light sinter for blast-furnaces should be greatly increased.—R. A. R.

Colloidal Chemistry and Flotation Problems. C. Berthelot. (Chimie et Industrie, 1942, vol. 48, Dec., pp. 315–322). The principles of colloidal chemistry are applied to the study of flotation problems. After studying the structures of metallic materials to be recovered by flotation, the foaming solutions and methods of clarification of washery waters are discussed.—R. F. F.

Enrichment of Ores by Flotation. R. Testut. (Annales des Mines et des Carburants, Mémoires, 1945, vol. 134, May-June, pp. 231–299). A detailed account is given of the flotation process with descriptions of crushing and grinding machinery and accessory plant in use at washeries. Reference is made to the treatment of different kinds of ores. Short descriptions are given of four French washeries with plans of the layouts of the plants.—J. C. R.

Application of Sintering of Ores Used by the Iron and Steel Industry. (Echo des Mines, 1946, Dec., p. 191). Sintering and sizing, as a preparation of ores for the blast-furnace, are discussed.—R. F. F.

Sintering Machines for the Iron and Steel Industry. W. J. Urban. (Blast Furnace and Steel Plant, 1947, vol. 35, July, pp. 809–812). Developments in individual components of sintering plants of the Dwight and Greenawalt types are reviewed briefly.—C. O.

Contribution to the Study of Oolitic Minette Ores of Lorraine. H. Laplanche. (Métallurgie, 1947, vol 79, Jan., pp. 5–9; Feb., pp. 7–13; Mar., pp. 9–14). A detailed account is presented of the occurrence, formation, structure, and chemical composition of the oolitic minette ores of Lorraine, and their enrichment by roasting and magnetic separation. Particuler reference is made to the Gredt process whereby the ore is roasted, but not fused, to a temperature not exceeding 1050° C. The roasted ore is said to be almost self-fluxing.—J. C. R.

Lean Ores—German Experience in Their Preparation. W. Luyken. (Iron and Steel, 1947, vol. 20, Oct., pp. 471–475). A short account is given of the nature and extent of the iron-ore resources of Germany. The most important of the processes used in the preparation of these ores for smelting are described. They include: Sizing, blending, and washing, *e.g.*, of Salzgitter ores; magnetic separation of dried ores, *e.g.* of the sandy Dogger ores at Peignitz; magnetizing-roasting and subsequent magnetic concentration, *e.g.*, of Salzgitter ores at Watenstedt; the roasting of spathic ores in shaft kilns, *e.g.*, at Siegerland; and the Krupp-Renn process. Brief mention is made of lean-ore smelting with acid slags.—C. O.

Operating Measures in the Sintering of Iron Ores. K. Kintzinger. (Iron and Steel Institute, 1947, Translation Series, No. 327). This is an English translation of a paper which appeared in Stahl und Eisen, 1943, vol. 63, June 10, pp. 453–456 (*see* Journ. I. and S.I., 1946, No. I, p. 37A.)—R. A. R.

The Smelting of Ilmenite in Germany. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1061: H.M. Stationery Office). An account is given of research work on the smelting of ilmenite in a batch-type rotary kiln, lined with magnesite. The ilmenite was briquetted with caustic soda, water, and coke or coal, and heated to 1400° C. for 4 hr. A high-carbon iron and a sodium titanate slag were formed. Insufficient work has been done to enable the yields and economics of the process to be determined.—C. O.

Concentrations of Manganese Ores from Lincoln County, Nev. B. K. Shibler, W. W. Agey, and A. O. Ipsen. (United States Bureau of Mines, 1947, Aug., Report of Investigations 4111). An account is given of an investigation into the possibility of beneficiating by ore-dressing methods the low-grade manganese ores found at Pioche and Culverwell, Lincoln County, Nevada. High-grade concentrates (48% manganese) were obtained from Culverwell ore by fine-grinding, flotation, and tabling.—C. O.

A New Pneumatic Separator. (Echo des Mines, 1947, Feb., pp. 27–28). The Birtley pneumatic separator type *D*13-18 for coal and ores is described—R. F. F.

The First Stamp Mills in English Industry. H. R. Schubert. (Journal of The Iron and Steel Institute, 1947, vol. 157, Nov., pp. 343–344). The early history of stamp mills for crushing ores is outlined. They were invented about 1500. The first application in England was in the lead-mining industry in Derbyshire by Burkhard Cranich in 1552. These mills were not used for crushing iron ores, but cinder from the forges was crushed in this manner for addition to the ore in the smelting process.—R. A. R.

TEMPERATURE MEASUREMENT AND CONTROL

The Colorimetric Estimation of Temperatures. M. Déribéré and M. de Buccar. (Chimie et Industrie, 1941, vol. 46, Nov., pp. 607–612). A list of "Thermocolour" pigments is given and new applications, based on the use of organic pigments and the application of the effect of temperature on luminescence, are suggested.—R. F. F.

A Fundamental Improvement in Temperature Measurement and Control. H. W. Bluethe. (Metal Progress, 1947, vol. 52, Oct., pp. 591–593). The necessity of using complicated mechanical relays between temperature-measuring instruments and control switches handicapped the development of industrial temperature controllers and recorders until the invention of the electronic "Capacitrol" circuit in 1935. Today modern instrumentation is within the reach of the smallest plant.—C. O.

The Measurement of the Temperature of Sliding Surfaces, with Particular Reference to Railway Brake Blocks. R. C. Parker and P. R. Marshall. (Institution of Mechanical Engineers, 1947, Preprint). An account is given of the theory of a lead sulphide pyrometer, developed for the measurement of rapidly varying temperatures between 200° and 900° C. The pyrometer has been used to determine the temperature of the surface of a railway tyre just as it emerged from beneath an applied brake. It was shown that surface temperatures of over 800° C. are an inevitable result of "strip" braking. In an attempt to eliminate strip braking by reducing the length of the block, it was found that reducing the block to one-quarter of its original length completely inhibited heat-spot formation and reduced the maximum temperature attained from over 800° C. to under 400° C.—C. O.

Temperature Determination of Molten Metal. G. Vennerholm and L. C. Tate. (American Foundryman, 1947, vol. 11, May, pp. 56–63). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 140).

The Liquid Steel Pyrometer. L. Sanderson. (Instrument Practice, 1947, vol. 2, Nov., pp. 18–21). A general account is given of the construction and use of the Schofield-Grace quick-immersion thermocouple.—C. O.

The Measurement of Elevated Temperatures in Metallurgy. J. Vivié. (Revue de Métallurgie, 1944, vol. 41, Oct., pp. 331–340). Pyrometers used in metallurgy are discussed, with special reference to optical and thermo-electric pyrometers.—R. F. F.

Pyrometer Tips. A. J. Benedict. (Industrial Heating, 1947, vol. 14, Oct., pp. 1624, 1648). Recommendations on the testing and maintenance of thermocouple installations are made.—R. A. R.

PRODUCTION OF STEEL

Experimental Steel Production with Oxygen-Enriched Blast in Bessemer Converter at Kuznetsk Steel Works. V. V. Konjakov. (Kislorod, 1946, vol. 3, No. 2–3, pp. 1–11: Engineers' Digest, 1947, vol. 8, Nov., pp. 383–384). Experiments in the use of oxygen-enriched blast in a 1½-ton Bessemer converter are described. The results indicated that the process can be applied to metal low in silicon. The steel produced was very low in nitrogen and had a high mechanical strength. The consumption of oxygen was about 40 cu. m. per ton of charge. Further work is required on means of reducing the phosphorus content of the product and prolonging the life of the tuyeres.—R. A. R.

The Possibilities of Using Liquid Fuels in Iron and Steel Works. W. Karlsson. (Värmlandska Bergsmannaföreningens Annaler, 1946, pp. 47–103). [In Swedish]. In 1945 the Research Council of Jernkontoret set up a committee to study problems relating to the use of liquid fuel in steelworks furnaces. This paper is a report on the committee's work. It deals comprehensively with the subject under the following headings: (1) The supply and demand for liquid fuel; (2) physical and chemical properties of liquid fuel; (3) combustion of mineral oils; (4) preheating the fuel and air; (5) burners; (6) application of liquid fuel; (7) storage and distribution; (8) advantages of liquid fuel; and (9) conversion coefficients for oil and other fuels.—R. A. R.

Evaluation of Openhearth Checkers. W. B. Bryant. (Iron Age, 1947, vol. 160, Nov. 13, pp. 76–81). The efficiencies of the common variations of the basket-weave and open-flue arrangements of open-hearth checker bricks are discussed from the viewpoints of cleanliness, stability, dimensional changes, and effectiveness. Data are given for the performance of 11 different installations.—C. O.

Production of Mixed Steels in Germany. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1165 : H.M. Stationery Office) A brief description is given of a process of steelmaking developed at the Hermann Göring Works. Approximately 100,000 tons were produced from April 1943 to December 1944. A chromium charge is produced in the electric furnace without slagging off in order to recover all of the charged chromium ; this heat consists of a full chromium scrap charge to which cheap ferrochromium (Cr 10–25%, C 5–6%, P 0·5% max.), produced in the blast-furnace, is added. The phosphorus content of the electric-furnace heat is disregarded. A straight carbon steel heat is made at the same time in a basic open-hearth. By slagging off frequently, this open-hearth heat is finished with phosphorus and sulphur below 0·01% and 0·02% respectively. The electric-furnace and open-hearth heats are then mixed in proportions to produce the required final analysis.—R. A. R.

Oxygen as a Combustion Aid in Gas-Fired Open-Hearth Furnaces. A. H. Leckie and M.W. Thring. (Iron and Coal Trades Review, 1947, vol. 155, Dec. 5, pp. 1095–1096). The replacement of a small or moderate proportion of the combustion air for open-hearth furnaces by directly injected oxygen and the requirements of burners for this purpose are considered. Designs of parts for introducing an annular ring of oxygen to oil-fired furnaces are suggested.—R. A. R.

Steel Production by Vacuum Electric Furnace at Heraeus Vacuumschmelzl Hanau. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1162 : H.M. Stationery Office).

Toolsteel Progress during Thirty Years. A. T. Clarage. (Metal Progress, 1947, vol. 52, Oct., pp. 568–571). A review is made of the changes in the practice in manufacturing tool steel which have taken place at the Chicago works of the Columbia Tool Steel Co. during the last thirty years.—C. O.

Reactions and Equilibria in the Acid Electric Furnace. J. Colin. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, Dec., pp. 405–418). After outlining acid electric-furnace practice the author considers in detail the behaviour of carbon, silicon, and manganese in the bath and shows how the silicon content can be rapidly determined.—J. C. R.

Electronic Frequency Converters for Induction Melting Furnaces. S. R. Durand. (Iron Age, 1947, vol. 160, Sept. 25, pp. 64–67, 134). Descriptions are given of the operation of several installations in which electronic frequency-changing equipment is used for induction furnaces melting alloy steels and non-ferrous alloys. —C. O.

The Reaction between Carbon and Oxygen in Liquid Iron. J. D. Fast. (Philips Research Reports, 1947, vol. 2, No. 3, pp. 205–227). The main subject of this paper is the reaction [FeO] + [C] ⇌ [Fe] + CO, the brackets indicating the components of a homogeneous liquid phase. Assuming a mixture of liquid iron and liquid FeO to possess a Gibbs entropy of mixing and a Van Laar heat of mixing, the activity of FeO in liquid iron is computed and compared with observed solubilities.—R. A. R.

Kinetics of Solidification of Killed Steel Ingots. J. W. Spretnak. (Transactions of American Society for Metals, 1947, vol. 39. pp. 569–619). *See* Journ. I. and S.I., 1947, vol. 156, July, p. 437.—R. A. R.

Theoretical Thermal Studies of Steel Ingot Solidification. V. Paschkis. (Transactions of American Society for Metals, 1947, vol. 38, pp. 117–147). The solution by the electrical-analogy method of three problems in the solidification of steel ingots is described. It is shown that (*a*) a carbon insert at the bottom of the mould gives more uniform freezing than a cast-iron bottom, (*b*) round ingots give much more uniform rates of solidification than rectangular ones, and (*c*) neither of two types of hot top is likely to cause bridging of the ingot below it.—C. O.

Structure, Segregation and Solidification of Semi-killed Steel Ingots. M. Tenenbaum. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2273 : Metals Technology, 1947, vol. 14, Sept.). The author reports the results of an investigation of the structure and segregation in a series of semi-killed steel ingots made under ordinary basic open-hearth conditions and with varying degrees of deoxidation. By regulating the manner and extent of ladle and mould deoxidation, ingots were produced the tendency of which towards gas formation ranged from a weak rimming action to a completely dead appearance. Throughout the range, the features observed could be interpreted according to known equilibrium relationships between the deoxidizing elements, the carbon and oxygen contents, and the pressures existing within the ingot.—C. O.

Solidification of Steel Ingots. J. R. Fleche. (Iron Age, 1947, vol. 160, Oct. 9, pp. 62–67 ; Oct. 23, pp. 55–62 ; Nov. 6, pp. 92–98 ; Nov. 13, pp. 94–98). Methods of calculating the time required for the complete freezing of steel ingots of almost any shape and of different carbon contents are explained.—R. A. R.

Ingot Moulds : Cast Iron or Graphite ? (Echo des Mines, 1947, May, pp. 75–76). Cast iron and graphite are compared as materials for the manufacture of ingot moulds.—R.F.F.

PRODUCTION OF FERRO-ALLOYS

Ferro-Alloy Production Furnaces at Elektrowerk Weisweiler. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 897 : H.M. Stationery Office.) Brief descriptions are given of the electric furnaces and the process at Elektrowerk Weisweiler for producing ferro-alloys, with special reference to ferrochromium.—R. A. R.

The German Ferro-Alloy Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 798 : H. M. Stationery Office). The technique and equipment of the German ferro-alloy industry are surveyed. This industry is based mostly on electric-furnace production. No special features of value to Great Britain were noted. —R. A. R.

FOUNDRY PRACTICE

Controlling Carbon in the Cupola. W. W. Levi. (American Foundryman, 1947, vol. 160, Oct., pp. 28–34). The variables which affect the carbon content of iron melted in the cupola are discussed at some length, and an equation, based on a knowledge of these variables, is developed for the calculation of the carbon content of the metal as tapped.—C. O.

Material Handling in Malleable Processing. N. J. Henke. (American Foundryman, 1947, vol. 11, May, pp. 48–52). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143.

Railway Bogies. (Iron and Steel, 1947, vol. 20, Nov. pp. 521–523). The use of cast-steel side-frames and bolsters in the production of railway-car bogies, in preference to the assembly of prefabricated parts, is discussed, and the advantages of the castings are enumerated.—J. R.

Practical Experiences with Synthetic Sands for Green-Sand Steel Castings. V. Koutecký. (Hutnické Listy, 1947, vol. 1, No. 7, pp. 151–155 ; No. 8, pp. 180–183). [In Czech].

Phenolic-Resin Binders—Utilization in Sand Cores for Ferrous Castings. J. E. McMillan and E. E. McSweeney. (American Foundryman, 1947, vol. 12, Oct., pp. 22–26). A short account is given of the chemistry of the phenol-formaldehyde types of resin, and of the physical properties of core sands bonded with such resins. Laboratory and foundry tests have shown that phenolic resins have the following advantages over oils for bonding: (1) They give higher strength; (2) they cure much faster, especially in thick sections; (3) they give off little gas on heating; and (4) they do not give off obnoxious gases or smokes when in contact with molten metal.—C. O.

Liquid Phenolic Resins for Casting Foundry Patterns. C. R. Simmons. (American Foundryman, 1947, vol. 11, May, pp. 94–96). The physical properties of phenol-formaldehyde resins are given and methods of using the resins to make patterns are described.—R. A. R.

Permanent Moulds for Foundries. H. Kalpers. (Technik, 1947, vol. 2, Oct., pp. 441–442). A description is given of the Büsselmann process of making moulds which can be used several times. The moulds are made of sands available in Germany, and they are given additional strength by extra ramming. The advantages of the moulds are outlined.—R. A. R.

The 'C' Process of Making Molds and Cores for Foundry Use. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1168: H.M. Stationery Office).

Why Cast Steel Centrifugally? J. F. B. Jackson. (Iron Age, 1947, vol. 160, Nov. 27, pp. 64–69). The advantages and limitations of centrifugal casting for steel and the difference in freezing rates when the mould is rotated (*a*) during pouring, and (*b*) after pouring, are pointed out.—R. A. R.

Ferrous Die-Castings—The Continuous Production Process. C. D. Pollard, H. A. Redshaw, and C. A. Payne. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 83, Nov. 20, pp. 237–245; Nov. 27, pp. 259–264). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 635.—R.A.R.

A Mechanical Method for Machine Repair. T. O. Oliver, jun. (Iron and Steel Engineer, 1947, vol. 24, Sept., pp. 55–57). A method for repairing castings in position, without the use of welding, is explained. Slots are cut transverse to the crack in the castings; into the slots are hammered specially shaped alloy-steel keys, which become work-hardened; the crack between the slots (which are ¾–1½ in. apart) is also filled with the alloy steel. With proper design and careful workmanship castings can be restored to their original strength by this means.—C. O.

A Realistic Appraisal of Precision Investment Casting Process. W. O. Sweeny. (Iron Age, 1947, vol. 160, Nov. 6, pp. 86–90). The author considers critically the commercial limitations of the investment casting process for the casting of high-melting-point alloys. He concludes that investment casting has a definite place in industry for the production of components of shapes or alloys which it is difficult to machine, forge, or form.—C. O.

Precision Casting by the Investment Moulding Process. H. K. Worner. (Australian Institute of Metals: Australasian Engineer, 1947, Aug. 7, pp. 60–65). A detailed description is given of the lost-wax method of precision casting—R. A. R.

Precision Casting—The Investment Moulding Process. (Australasian Engineer, 1947, Sept. 8, pp. 81–82). The lost-wax precision-casting process is described.—C. O.

Present and Future Heating Applications in Precision Casting. P. L. Butler. (American Gas Association: Industrial Heating, 1947, vol. 14, Aug., pp. 1290–1294). The control of the heating operations in the lost-wax method of precision casting is discussed.—C. O.

Rôle of Centrifugal Casting in Transforming Pigs to Pipe. G. E. Stedman. (Steel, 1947, vol. 121, Oct. 13, pp. 91–94, 122–124). An illustrated description is given of the plant and processes at the foundry of the National Cast Iron Pipe Company, where pipes from 3 to 24 in. in dia. up to 18 ft. long are made by the deLavaud centrifugal casting system.—R. A. R.

Pinholes in Steel Castings. J. Mackievič. (Hutnické Listy, 1947, vol. 1, No. 11, pp. 245–249; No. 12, pp. 273–276). [In Czech]. Tests are described which showed that pinholes in steel castings were caused by nascent hydrogen coming from the green sand when the molten metal was poured into it. Control of the properties of sand is insufficient to eliminate the trouble; the metal should be completely deoxidized, preferably with aluminium.—R. A. R.

The Economics of Mechanical Shakeout. J. L. Yates. (Iron Age, 1947, vol. 160, Nov. 13, pp. 88–93). The possibilities afforded by mechanical shaking-out of moulds for reducing costs and improving working conditions in the foundry are discussed.—C. O.

The Problem of Removing Risers from Castings in Foundries. J. Mackievič. (Hutnické Listy, 1946, vol. 1, No. 6, pp. 121–129). [In Czech]. The use of a narrow neck connecting the riser to the casting for both ferrous and non-ferrous metals is discussed, and numerous examples are described and illustrated.—R. A. R.

Technical Centre for the Foundry Industry of France. M. Le Thomas. (Hutnické Listy, 1947, vol. 1, No. 7, pp. 148–151). [In Czech]. The post-war organization of Le Centre Technique des Industries de la Fonderie in Paris is described.—R. A. R.

Foundry Training Course for College Graduates. (American Foundryman, 1947, vol. 11, May, pp. 97–99). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 294.

Education of Apprentices in Foundries. V. Oliverius. (Hutnické Listy, 1947, vol. 1, No. 11, pp. 249–253). [In Czech].

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Accurate Control Spells Success in Heat-Treating. C. C. Roberts. (Machinist, 1947, vol. 91, Nov. 8, pp. 981–982). A brief description is given of a battery of six Upton electric salt-bath furnaces recently installed at Dayton, Ohio, The furnaces, designed for all types of heat-treatments at different temperatures, are electronically controlled.—C. O.

Thermal Control of Gas-Fired Furnaces for the Heat-Treatment of Metals. J. Molinié. (Annales des Mines et des Carburants, 1943, Series 14, vol. 2, pp. 233–258). The causes of heat losses in the operation of gas-fired furnaces are analysed and means of eliminating wastage are discussed.—J. C. R.

A Laboratory Study of Quench Cracking in Cast Alloy Steels. M. C. Udy and M. K. Barnett. (American Society for Metals, 1947, vol. 38, pp. 471–485). An investigation of the effect of chemical composition and heat-treatment upon the sensitivity of alloy steels to quench cracking is described. Notched cylindrical specimens were quenched in a special fixture, immersed in an etching reagent for 1 hr., and split along their axes. Cracks caused by the quenching were shown by the etching. Carbon was found to be the element giving the greatest tendency to cracking; manganese, chromium, and phosphorus were detrimental, but to a lesser degree

than carbon; sulphur, silicon, nickel, molybdenum, and aluminium showed little effect in the ranges studied, nor did the usual additions of boron. High austenitizing temperatures increased the cracking tendency, but prolonged austenitizing just before quenching, and a high-temperature homogenizing treatment, lessened it.—C. O.

Heat-Treatment Problems. E. H. Francis. (Australian Institute of Metals : Australasian Engineer, 1947, Sept. 8. pp. 56–58). The author discusses problems he has encountered in his experience of industrial heat-treatment, with particular reference to the effect of austenite retained on quenching.—C. O.

Advancements in Industrial Heat Treating Equipment. L. A. Lindberg. (Metal Progress, 1947, vol. 52, Oct., pp. 586–590). Present-day heat-treatment equipment is compared with that in use in 1917.—C. O.

Development of Furnaces with Recirculating Atmospheres. J. Ade. (Metal Progress, 1947, vol. 52, Oct., pp. 594–598). The forced-atmosphere-circulation furnace was developed to meet the need for a heat-treatment furnace operating at a temperature below that satisfactory for efficient transfer of heat by radiation from incandescent surfaces. The author describes several types of furnace in which the hot atmosphere is circulated at speeds of up to 100 m.p.h., including a recent improved type in which the direction of circulation is reversed at intervals.—C. O.

High-Frequency Heating. M. Fourment. (Chimie et Industrie, 1942, vol. 47, Mar., pp. 316–324). The applications of high-frequency heating are discussed with special reference to heat-treatment, fusion, and volatilization.—R. F. F.

Skin-Hardening—Some Aspects of the High-Frequency Induction Process. R. J. Brown. (Automobile Engineer, 1947, vol. 37, Oct., pp. 389–390). Practical aspects of the surface-hardening of steel components, such as its relation to case-hardening, the design of coils, and the selection of the types of steel for the process, are discussed briefly.—C. O.

Induction Heating by High Frequency Methods. O. F. Gullick. (Machinist, 1947, vol. 91, Oct. 11, pp. 831–837; Oct. 18, pp. 867–872). The principles, methods of application, and limitations of industrial heating by high-frequency methods are discussed and equipment is described.—J. R.

Selector Chart for Induction Heating and Melting Equipment. (Iron Age, 1947, vol. 160, Oct. 16, p. 139). A chart is given as a guide for the selection of the type and size of induction-heating equipment required for specific metallurgical operations.—C. O.

Examples of Metallurgical Progress at International Harvester Co. (Metal Progress, 1947, vol. 52, Oct., pp. 614–624). This paper, which was written by members of the staff of the International Harvester Co., gives examples of recent advances in industrial heat-treatment techniques, such as the use of induction heating for hardening crankshafts and for soldering; the continuous heat-treatment of ball-bearing race rings; and the annealing of white iron castings in continuous gas-fired furnaces in 14½ hr.—C. O.

Overheating and Burning and Their Correction. L. Colombier. (Bulletin du Cercle d'Études des Métaux, 1942, vol. 3, Mar., pp. 146–158). Small test-pieces of a carbon steel, a self-hardening chromium–molybdenum–nickel structural steel, and a chromium–nickel steel were heated for periods varying from 1 to 4 hr. to temperatures up to 1275° C. and then subjected to different cooling, quenching, and annealing treatments. The appearance of the grain on fracture and results of impact tests are tabulated. The effect of an addition of 0·01% of aluminium was to retard grain growth and to render more difficult the recovery of the original structure on annealing after overheating.—J. C. R.

The Overheating of Steel. L. Colombier. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, Dec., pp. 388–404). After discussing the structure of over heated steels, the author considers the connection of the following factors with overheating phenomena : (*a*) The influence of the method of cooling after heating to high temperatures; (*b*) the influence of the method of production; (*c*) the influence of various impurities; (*d*) temper-brittleness. He then attempts to explain overheating as a combination of two phenomena : (*a*) Grain growth with increased temperature, promoted by some elements and inhibited by others; (*b*) the persistence of a heterogeneous lattice due to the presence in great or small concentrations of certain elements dissolved in the austenite, which affect the surface tension. This heterogeneity is of greater importance when the grain is large and the temperature high as in these two cases the surface tension is smaller.—J. C. R.

Some Developments in the Annealing of Malleable White Iron. I. Jenkins. (Metal Treatment, 1947, vol. 14, Autumn Issue, pp. 175–193). The principles of the production of whiteheart malleable iron are explained at length, and an account is given of the development of the modern gaseous-annealing process and the plant required for it.—C. O.

Heat-Treating Aircraft Blades Made from Steel Tubing at American Propellor Corporation. (Industrial Heating, 1947, vol. 14, June, pp. 916–928, 952; July, pp. 1075–1080). The heat-treating equipment used in the various stages of the fabrication of hollow chromium–molybdenum–nickel steel aircraft propeller blades from seamless tubing at the Toledo, Ohio, plant of the American Propellor Corporation is described.—C. O.

Protective Atmospheres Generated from Paraffin. (Machine Shop, 1947, vol. 8, Sept., pp. 112–115). A recent development in the production of protective atmospheres in heat-treatment furnaces has been the introduction of a burner designed for the combustion of paraffin. The equipment and method are described and test results illustrated.—J. R.

New Methods of Heat Treatment. L. Grenet. (Echo des Mines, 1947, Aug., pp. 129–130). This is a brief review of flame and high-frequency hardening.—R. F. F.

Bainitic Hardening of High Speed Steel. C. K. Baer and P. Payson. (Transactions of American Society for Metals, 1947, vol. 39, pp. 488–513). The forms of heat-treatment which produce bainite in high-speed steels were studied and a treatment is described by which a structure consisting almost entirely of tempered bainite can be produced. Tools treated in this way gave a very good performance in cutting tests.—R. A. R.

Carburized Cases of Hypoeutectoid Carbon Content. P. C. Rosenthal and G. K. Manning. (Transactions of American Society for Metals, 1947, vol. 39, pp. 801–815). A method of restricting the maximum carbon content of carburized cases to the range 0·80–0·40% by adding silicon-bearing materials plus a chloride to the carburizing compounds was investigated, and the results obtained are reported.—R. A. R.

Carbide and Oxide in Surface Zones of Carburized Alloy Steels. A. Hultgren and E. Häggland. (Transactions of American Society for Metals, 1947, vol. 39, pp. 820–837). This paper presents the results of carburizing tests for 50 hr. at 900° C., in a charcoal barium-carbonate compound, in a mild carburizing compound, and in hydrocarbon gas, on a series of alloy steels.—R. A. R.

Sulphide Penetration in the Carburization of Steel. A. Preece and K. J. Irvine. (Journal of The Iron and Steel Institute, 1947, vol. 57, Nov., pp. 336–343). The mechanism of sulphide penetration into steel during carburization has been demonstrated by experiments in which suitably coated specimens of Armco iron have been exposed to carburizing mixtures of carbon monoxide and carbon dioxide. By adjusting the gas mixture in contact with specimens, deep-seated inclusions of iron sulphide have been converted into iron oxide. Iron sulphide inclusions have also been converted into manganese sulphide by prolonged treatment at 1000° C. The results have also shown interrelated effects between carbon, sulphur, and oxygen which may be of significance in the segregation and homogenization of steel castings.

Surface Hardening of Steels by Cementation Followed by Nitriding. J. D. Venturini. (Comptes Rendus, 1947, vol. 224, Jan. 13, pp. 118–120). An account is given of the results of hardness tests on carbon steels after subjection to the following treatments: (*a*) Heating between 850° and 950° C. in contact with ferro-aluminium and other ferro-alloys; (*b*) grinding and polishing; and (*c*) nitriding by ammonia at a temperature between 475° and 550° C. for periods of 1½–3 hr.—J. C. R.

Heat Treating by Electric Salt Bath Furnace Process. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Aug., pp. 21–22). Details are given of an installation consisting of six electrically heated salt-bath furnaces, designed to enable any type of heat-treatment work to be carried out in it.—C. O.

Electrode Salt Baths. R. A. P. Misra and R. O'Donoghue. (British Engineering Export Journal, 1947, vol. 30, Sept., pp. 366–373). An illustrated account is given of some British types of electrode salt-bath furnaces for hardening, annealing, quenching, preheating, brazing, and carburizing. Various salts, which are electrical conductors when molten, are used according to the temperature of the treatment undertaken. Temperatures between 550° and 1400° C. can be maintained, but different inputs are required for different temperature ranges and an equipment is normally supplied for one particular application. Temperatures below 550° C. cannot be used because salts suitable for this lower range are subject to electrolytic action and cause rapid scaling of ferrous metals. Suitable temperatures for various treatments are given and particulars are included of the outstanding features of the Wild-Barfield, Birlec, and Efco-Ajax-Hultgren furnaces.—R. E.

Rectification of Neutral Salt Baths. P. H. Kramer. (Iron Age, 1947, vol. 160, Oct. 23, pp. 52–54). A description is given of the Neutra-Gas process of rectifying neutral salt baths for case-hardening. The principle is different from that of former rectifiers since, instead of removing the oxides by forming a reaction product insoluble in the bath, Neutra-Gas reconverts the oxides to the original chlorides. The gas employed is methyl chloride, which breaks down on heating to form hydrochloric acid and ethylene; the latter burns at the surface of the bath. The equipment required is simple and the cost is low.—R. A. R.

High Speed Annealing of Stainless Bars and Tubes. E. S. Kopecki. (Iron Age, 1947, vol. 160, Oct. 16, pp. 143–149). Details are given of the construction and operation of two similar gas-fired continuous annealing-furnace installations, one used at the Massillon, Ohio, works of the Republic Steel Corporation for annealing stainless-steel bars, and the other at the Brackenridge, Pennsylvania, works of the Allegheny Ludlum Steel Corporation for stainless-steel tubes. The furnaces enable very exact control to be maintained over metal quality, and their use has resulted in fuel savings and an improvement in working conditions.—C. O.

Stress-Relieving Cylinder Blocks in Continuous Furnace. (Industrial Heating, 1947, vol. 14, Aug., pp. 1252–1253). A very short description is given of a continuous gas-fired furnace for the stress-relieving of automobile cylinder-block castings.—C. O.

Relatively New Method for the Study of the Behaviour of Steels during Hardening. L. Grenet. (Echo des Mines, 1947, June, p. 91; July, p. 107). The author critically discusses Davenport and Bain's curves.—R. F. F.

Observations on the Hardening of Steels. L. Grenet. (Echo des Mines, 1946, Feb., p. 24; Mar., p. 41; Apr., p. 56; May, p. 69; June, p. 85). The hardening of steels is discussed, and quenching in water, oil, and hot and cold liquids compared.—R. F. F.

Hardening of Tool Steels. L. Grenet. (Echo des Mines, 1946, Nov., pp. 173–174; Dec., p. 192; 1947, Jan., pp. 11–12). The theory and practice of hardening tool steels are described.—R. F. F.

Review of the Hardening of Steels. L. Grenet. (Echo des Mines, 1947, Feb., p. 30; Mar., pp. 43–44; Apr., pp. 62–63).—R. F. F.

Notes on the Hardening of Stainless Steels Used in Cutlery. A. Bufferne. (Echo des Mines, 1947, May, pp. 76–77; June, pp. 92–93). The practice of hardening stainless steels and the furnaces used are described.—R. F. F.

Interrupted Quenching as a Metallurgical Tool. C. H. Lekberg. (American Gas Association: Steel, 1947, vol. 121, Oct. 27, pp. 79, 107–111). The principles of austempering, isothermal quenching, and martempering are briefly outlined and the types of furnace equipment required for these processes are discussed. A salt-bath quenching furnace, with gas-fired suction-type immersion burners, designed for interrupted-quenching operations is described.—C. O.

Quenching Media and Methods. H. L. Flynn. (Machinist, 1947, vol. 91, Nov. 15, pp. 1001–1012). A comprehensive review is made of present-day steel-quenching techniques and equipment.—C. O.

Soluble Oil in Flame Hardening Operations. S. Smith. (Iron and Steel Engineer, 1947, vol. 24, Oct., pp. 59–63). The use of water-soluble oils for quenching in continuous flame-hardening operations where water would give too drastic a quench or where ordinary oils would ignite is described.—C. O.

The Tempering of High Alloy Steels. G. A. Roberts, A. H. Grobe and C. F. Moersch, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 521–546). *See* Journ. I. and S. I., 1946, No. II, p. 137A.—R. A. R.

FORGING, STAMPING, DRAWING, AND PRESSING

Modern Forging Practice. F. E. Stokeld and K. Fidler. (Journal of the Birmingham Metallurgical Society, 1947, vol. 27, Sept., pp. 354–377). Die forgings, precision forgings, upset forgings, etc., are discussed by F. E. Stokeld, and the production of drop-forged articles is outlined by K. Fidler.—J. R.

How to Predict Suitability and Determine Method of Martempering Hypoeutectoid Steel. D. Rosenblatt. (Steel, 1947, vol. 121, Oct., pp. 94–96, 121–126). A method of calculating the possibility of applying the martempering process to specific hypo-eutectoid steel components is explained in detail, with examples.—C. O.

Forming Steel by Cold Extrusion. (Steel, 1947, vol. 121, Oct. 20, pp. 93, 128). The successful use in Germany of cold extrusion for the manufacture of steel cartridge

cases and aircraft-landing-gear cylinders is briefly described.—C. O.

Folding in the Cupping Operation. W. M. Baldwin, jun., and T. S. Howald. (Transactions of American Society for Metals, 1947, vol. 38, pp. 757–788). A theoretical and experimental investigation of the tendency of a blank to fold when drawn into a cup is reported. The effects of die contour, reduction in diameter, and blank thickness were studied for blanks of copper, brass, aluminium, and low-carbon steel. It was found possible to predict the tendency of a blank to fold from a knowledge of the stress-strain diagram of the metal.—C. O.

High Temperature Disc Forging Developments for Aircraft Gas Turbines. L. B. Fonda. (American Society of Mechanical Designers: Steel Processing, 1947, vol. 33, Aug., pp. 469–473, 486, 491, 500–502; Sept., pp. 564–567). The results of bursting tests on forged jet-engine turbine wheels made of several different high-temperature alloys are reported. The most important factor in giving high and consistent bursting speeds was found to be ductility, and the best method of obtaining ductility was control of grain flow during forging.—C. O.

Determination of Strength of Blow of Die Hammers. F. Drastík. (Hutnické Listy, 1947, vol. 2, No. 3, pp. 57–61). [In Czech]. Empirical formulæ are developed for calculating the energy of the blows of die hammers for forging carbon and alloy steels.—R. A. R.

Ring Gears Formed from Steel Bar Stock. K. Rose. (Materials and Methods, 1947, vol. 26, Aug., pp. 75–77). An illustrated description is given of a method for the manufacture of six ring gears from a 22-ft. length of hot-rolled steel bar.—C. O.

Press-Shaping Bath Tubs. (Steel, 1947, vol. 121, Oct. 20, pp. 90–91). The forming in two strokes on a 450-ton crank press of bath tubs from 14-gauge, deep-drawing-quality, cold-rolled, 40 × 80-in. steel sheets is illustrated.—C. O.

Precision Drop Forging of High Temperature Alloys. S. G. Demirjian. (Materials and Methods, 1947, vol. 26, Sept., pp. 68–71). The problems involved in the forging of turbine buckets for jet engines are discussed. A process for forging buckets from Hastelloy B bar stock by upsetting in a solid die is briefly described, and mention is made of the use of the cobalt-base S-816 alloy, forging under controlled atmospheres, and die-design.—C. O.

Production Processes—Their Influence on Design. Part XXIX—Roll Die Forging. R. W. Bolz. (Machine Design, 1947, vol. 19, Nov., pp. 129–134). An illustrated account is given of the applications of the roll-die-forging or die-rolling process in the manufacture of forging blanks and finished and semi-finished machine parts.—C. O.

Drop Forgings (Appendix No. 14 to C.I.O.S. Report XXXII-119). (Combined Intelligence Objectives Sub-Committee, 1947; File No. XXXIII-72: H.M. Stationery Office). A report is presented on machinery and processes seen in the course of visits to German works producing drop forgings.—R. A. R.

Nitrided Steel Hot Formed After Heat Treatment. J. Frazier. (Materials and Methods, 1947, vol. 26, Oct., pp. 80–83). A detailed account is given of the manufacture of a nitrided sleeve valve for an internal-combustion engine. After the Nitralloy-125 blank has been nitrided, it is heated in a controlled atmosphere at 1950° F. for 3 min., and then simultaneously formed and quenched in a water-cooled die.—C. O.

A Survey of High Pressure Equipment Designs in Germany. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1067: H.M. Stationery Office).

Investigation of German Hosiery Needle Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1506: H.M. Stationery Office). Descriptions are given of the machinery and processes in use at the needle-making factory of Franz Arndt at Iserlohn, and Groz Beckert, Ebingen.—R. A. R.

Lubrication in Drawing Operations—A Symposium. E. A. Evans, H. Silman, and H. W. Swift. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1947, vol. 24, Oct., pp. 1995–2002; Nov., pp. 2209–2213, 2216: Engineering, 1947, vol. 164, Nov. 7, pp. 454–455; Nov. 14, pp. 477–479). The functions of a lubricant in a drawing operation are considered to be: (1) To ensure that the stresses induced in the metal are kept below its strength; (2) to ensure a satisfactory surface condition; and (3) to prevent wear of the press tools. An account is given of the properties and characteristics of the common lubricants, of experimental methods of comparing them, and of industrial methods for removing oil and grease from metals.—C. O.

The Production of Coiled Springs. (Machinery, 1947, vol. 71, Nov. 13, pp. 535–540; Nov. 27, pp. 591–597). The methods employed by Messrs. Geo. Salter and Co., Ltd., for the production of coiled springs of all types and sizes are described and illustrated.—C. O.

Successful Drawing and Redrawing Thin Metal Stampings. W. C. Mills. (Machinist, 1947, vol. 91, Nov. 22, pp. 1038–1042). Methods of preventing tears and wrinkles during the drawing and redrawing of thin stampings, by good design of the die and product, are illustrated.—C. O.

Some Recent Applications of Cemented Carbide. K. R. Beardslee. (Machinery, vol. 71, Nov. 6, pp. 507–512). The author indicates some of the present-day uses of cemented carbides. His examples include dies for wire-drawing, stamping, pressing, and forging, punches, and parts subjected to erosion, such as guides for textile threads, valves, and nozzles.—C. O.

Technical Progress in the Wire Industry. R. S. Brown. (Manchester Metallurgical Society: Wire and Wire Products, 1947, vol. 22, Sept., pp. 658–664). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 578.

Modern Electrical Control for Wire Mill Machinery. O. M. Bundy. (Iron and Steel Engineer, 1947, vol. 24, Oct., pp. 64–71). Modern practice in the control of electrical equipment for wire-drawing machinery is discussed under the headings: (*a*) Single-motor 1- or 2-die machines; (*b*) single-motor slip machines; (*c*) single-motor non-slip machines; and (*d*) multiple-motor non-slip machines.

Back-Pull Wire Drawing—A Critical Review of Literature. J. G. Wistreich. (Journal of The Iron and Steel Institute, 1947, vol. 157, Nov., pp. 417–428). The paper is an instalment of a critical survey of literature on wire drawing and is intended to explain the salient features of drawing with back pull and to provide a basis for further research. For this reason neither patents nor existing machine designs are considered. In reviewing published papers emphasis has been laid on results bearing on the practice of drawing with back pull, *i.e.*, on the effect of the latter on forces, power consumption, die wear, and on the properties of wire. It is found that the application of back pull brings about a reduction in the die load and—with the aid of a suitable design of the drawing machine—in the power consumption. The literature on the effect of back pull on the mechanical properties of the wire is not conclusive; on the whole, back pull does not appreciably influence the quality of wire as judged by conventional tests.

The Aetna Wire Drawing Unit. E. J. P. Fisher and A. L. Thurman. (Wire and Wire Products, 1947, vol. 22, Aug., pp. 582–587; Sept., pp. 665–668, 679–681). The development of a continuous non-slip wire-drawing machine by the Aetna-Standard Engineering Co., Youngstown, Ohio, is traced and the operation of a multi-unit installation is described in detail.—C. O.

The Application of Bonderizing-Drawing in the Wire Industry. (Metalloberfläche, 1947, vol. 1, Jan., p. 18). The advantages of phosphatizing wire before drawing and using a soap lubricant in the drawing die are discussed.—R. A. R.

Steel Wire. Use of Borax in the Dry Drawing Process. (Iron and Steel, 1947, vol. 20, Nov., p. 527). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 637.

Improvements in the Wire Industry in the Last 10 Years. (Wire and Wire Products, 1947, vol. 22, Oct., pp. 802–824). A Symposium on recent developments in the wire-drawing industry was presented at the annual convention of the Wire Association in Chicago, Illinois, in October, 1947. Abstracts of the papers dealing with ferrous materials follow.—C. O.

Stainless Steel Wire. J. K. Findley. (*Ibid.*, pp. 804–808). Improvements in equipment for the heat-treatment and drawing of stainless-steel wire brought about during the last ten years are briefly indicated.—C. O.

Low and High Carbon Steel Wire. (*Ibid.*, pp. 808–812). The aspects of carbon-steel wire-drawing practice in which the most outstanding improvements have taken place in the past decade are indicated. They include the quality of the steel used, heat-treatment, rod preparation, and drawing machinery.—C. O.

Advances in the Wire Drawing Field During the Past 10 Years. E. Glen. (*Ibid.*, pp. 812, 819–823). Brief mention is made of improvements in cleaning, baking, liming, annealing, and lubrication practice and the design of dies and equipment for wire drawing which have been made in the last decade.—C. O.

Hi-Carbon Wire Drawing. J. H. Janssen. (Wire and Wire Products, 1947, vol. 22, Oct., pp. 764–766). An investigation of the effect of drafting practice on the torsional strength of high-carbon patented rope wire is briefly reported. It is shown that heavier drafting, *i.e.*, the use of dies of larger angle than is normal, and water-cooling of the blocks both tend to give wire of improved mechanical properties.—C. O.

MACHINERY FOR IRON AND STEEL PLANT

Maintenance in the Boilerhouse. L. D. Hoadley. (Iron and Steel Engineer, 1947, vol. 24, Sept., pp. 51–52). The organization of the boiler maintenance in the Zug Island blast-furnace plant of the Great Lakes Steel Corporation is described in outline.—C. O.

Emergency Load Control of Power Houses. K. S. Kuka. (Iron and Steel Engineer, 1947, vol. 24, Sept., pp. 82–85). A system is described whereby the electrical loads in a large centralized steelworks may be remotely controlled to prevent overloading because of generator or boiler-house troubles. This system, which is automatic, utilizes only standard equipment.—C. O.

Economics of High Pressure Steam for Steel Mill Power. F. A. Sawyer. (Iron and Steel Engineer, 1947, vol. 24, Oct., pp. 44–49). The economic advantages of plant operating at steam pressures above 500 lb./sq. in. gauge for the generation of electricity for steelworks are set forth. They include reductions in labour costs, the amount of circulating water required, and fuel requirements.—C. O.

Maintenance of Steel Mill Cranes. A. J. F. MacQueen. (Iron and Steel Engineer, 1947, vol. 24, Oct., pp. 72–76). General maintenance practice for general-service overhead travelling cranes of 5–30 tons capacity and 50–100 ft. span is outlined and specific problems such as lubrication, gearing, cables, switches, and brakes, are discussed.—C. O.

Fifty Years of Crane Construction. M. Bänninger. (Von Roll Mitteilungen, 1944, vol. 3, Dec., pp. 105–117). A review is presented of the cranes which have been constructed by Ludw. von Rollschen Eisenwerke, A.G., during the last 50 years. Many of the latest types of lifting machinery are described and illustrated.—R. A. R.

Electrical Aspects of Overhead Travelling Cranes. G. V. Sadler. (Institution of Electrical Engineers, 1947, Preprint). The paper serves as a guide to engineers intending to install electrically operated lifting equipment over an area of factory, warehouse, stockyard, or power plant. Emphasis is laid on performance rather than design.—R. A. R.

WELDING AND FLAME-CUTTING

Contribution to the Study of the Phenomena of Expansion and Shrinkage. P. Berthet. (Soudure et Techniques Connexes, 1947, vol. 1, Jan.–Feb., pp. 25–33). Details are given of a study of welding practice in aircraft construction with particular reference to shrinkage. Tests were carried out on unalloyed steel, chromium-molybdenum steel and various aluminium–magnesium alloys, and the shrinkage of large structures was computed by using the results for individual joints. Arc- and gas-welding were used and the effects of changes in welding procedure were studied. An abridged translation appears in Welding Journal, 1947, vol. 26, July, pp. 370s–371s.—J. C. R.

Radiology of Joints in Welded Piping for Power Plants. E. Thomas. (Institution of Mechanical Engineers, 1947, Preprint). The techniques of inspecting joints in welded piping either in the shop or on site by means of X- or gamma-rays are described.—C. O.

Nonmagnetic Arc Welding Joints between Mild Steel Plates. O. C. Frederick. (Steel, 1947, vol. 121, Oct. 13, pp. 85, 124). In the construction of electrical equipment it is sometimes necessary to break up magnetic circuits; this can be done by arc-welding a seam of non-magnetic material in a magnetic steel structure. In this investigation the minimum root gap of the groove to be welded to produce a non-magnetic band between mild-steel plates of different thicknesses was determined using stainless-steel and aluminium-bronze electrodes.—R. A. R.

Flash Welding Theory and Practice. W. H. Cochran. (Iron Age, 1947, vol. 160, Oct. 16, pp. 150–154). An account is given of the principles of flash-welding.—C. O.

Practical Importance of Hydrogen in Metal-Arc Welding of Steel. S. A. Herres. (Transactions of American Society for Metals, 1947, vol. 39, pp. 162–189). *See* Journ. I. and S.I., 1946, No. II, p. 135A.—R. A. R.

Welding Steel Trailer Door Frames Increases Strength, Saves Weight. A. F. Denham. (Materials and Methods, 1947, vol. 26, Aug., pp. 93–96). The mass-production of steel trailer doorframes is illustrated. The frames are fabricated by spot-welding from hot-rolled, pickled, and oiled mild-steel angle bars.—C. O.

Welding Hardenable Steels. O. T. Barnett. (Steel, 1947, vol. 121, Sept. 22, pp. 72–74, 110; Sept. 29, pp. 80–84, 114–117). A system worked out at Lehigh University for assessing the weldability of hardenable steels is discussed, with examples of its use. In the second part of the article the author deals with the

application of S-curves in developing welding techniques, heat-treatments, and lime-ferritic low-hydrogen electrodes.—C. O.

Welding in the Iron Foundry. H. E. Schultz. (Seventh New England Foundry Conference : Foundry, 1947, vol. 75, Oct., pp. 78–80, 136, 139). The merits of welding cast iron by the oxy-acetylene process with cast-iron rods, and arc welding with nickel or copper–nickel electrodes are compared.—R. A. R.

Weld Repair of Gray Iron Castings. C. E. Phillips. (Iron Age, 1947, vol. 160, Oct. 23, pp. 49–51). A procedure for making machinable welds on grey-iron castings using electrodes consisting of a pure nickel core wire, sheathed in pure copper, and flux-coated, is described.—R. A. R.

Reclaiming a Broken 54-in. Mill Pinion. W. W. Scherer. (Iron and Steel Engineer, 1947, vol. 24, Sept., pp. 58–61). A detailed illustrated description is given of the repair of a 54-in. double-helical mill pinion which had fractured in a plane at right angles to its axis. The fractured surfaces were ground and accurately positioned 3¼ in. apart by means of a centring pin. The gap was then filled by molten steel from four 2350-lb. thermit-welding crucibles.— C. O.

Temperature Chart for Soldering, Brazing and Welding Processes. R. C. Hitchcock. (Product Engineering, 1947, vol. 18, Oct., p. 171). A chart is given which indicates the melting points and compositions of the common brazing and soldering alloys, and the temperature limits and fluxes suitable for various joining processes.—C. O.

Kolene Process Aids Silver Brazing of Cast Iron. E. R. Atkinson. (Iron Age, 1947, vol. 160, Nov. 6, p. 85). The Kolene process for the preparation of cast-iron surfaces for silver brazing is described briefly. It consists of a cycle of oxidation and reduction brought about by passing an electric current through the parts to be brazed while they are immersed in a tank of molten salts.—C. O.

Design Possibilities in the Silver Brazing of Cast Iron. H. Frick. (Product Engineering, 1947, vol. 18, Oct., pp. 128–132). Brief mention is made of the Kolene silver-brazing process, which enables alloys such as stainless steel, Monel metal, Inconel, and Everdur to be firmly bonded to grey cast iron. The possibilities which the process offers for the improvement of engineering design and reduction in foundry and machining costs are illustrated by examples.—C. O.

Furnace Brazing—A Detailed Review of Production Equipment and Methods. H. D. Hendrick. (Automobile Engineer, 1947, vol. 37, Oct., pp. 365–371). The author discusses the design and assembly of components for brazing, brazing alloys and fluxes, continuous brazing furnaces, and controlled atmospheres for brazing.—C. O.

A Study of Furnace Brazing as Applied to 12% Chromium Low Carbon Steel. T. H. Gray. (Transactions of American Society for Metals, 1947, vol. 39, pp. 453–478 : Steel, 1947, vol. 121, July 21, pp. 104–106, 124, 127). The results of tensile and rupture tests on 12%-chromium steel brazed with copper and copper alloys are presented.—R. A. R.

Induction Soldering Speeds Kitchen-Utensil Production. L. Gise and J. R. Stewart. (Industrial Heating, 1947, vol. 14, July, pp. 1098–1102). Details are given of a method of joining the shanks and blades of stainless-steel kitchen utensils by silver-soldering in an induction furnace.—C. O.

Applications of Flux-Injection Cutting to Stainless Steel. G. E. Bellew. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Aug., pp. 16–19). A short account is given of the principles of the flux-injection method of cutting steel, in which a chemical flux is fed into an ordinary oxygen-cutting stream to slag off the refractory oxides which are formed. Applications of the process to the cutting of stainless steel are illustrated.—C. O.

MACHINING AND MACHINABILITY

Brinell Hardness Does Not Measure Machinability. G. Schlesinger. (Machinist, 1947, vol. 91, Nov. 8, pp. 967–978). The results of tests of the effect of hardness on machinability made in the United States, Great Britain, and on the Continent are presented and discussed. It is concluded that the machinability index and not the Brinell hardness number should be used to estimate the machining properties of steels and cast irons.—C. O.

A Critical Commentary on German Wartime Work on Machinability. K. J. B. Wolfe. (Iron and Coal Trades Review, 1947, vol. 155, Oct. 17, pp. 733–740). A wide survey is made of research carried out in Germany during the war years upon (*a*) the behaviour of metals and alloys during mechanical cutting by recognized processes, (*b*) the behaviour of the cutting tool in such operations, and (*c*) the mechanisms of the cutting processes. The general conclusion is that no results of outstanding practical merit emerged from the German work on these subjects, though much of it is of academic interest.—J. R.

Machining Stainless Steel Valves. A. P. Nelson. (Machinery, 1947, vol. 71, Oct. 30, pp. 479–483). The tools and best practice for turning, drilling, and threading stainless-steel parts are described.—R. A. R.

Machining Austenitic Heat-Resisting Steel. H. L. Wainwright. (Machinery, 1947, vol. 71, Oct. 23, p. 465). Results of tests carried out with high-speed-steel and cemented-carbide tools on jet-engine components provide useful information upon the machining of austenitic heat-resisting steel.—J. R.

Hard-Chromium-Plating of Lathe Tools—Advantages and Limitations. H. Schallbroch and W. Hielscher. (Zeitschrift des Vereines deutscher Ingenieure, 1944, vol. 88, June 10, pp. 321–326). Machining tests were made using chromium-plated 10%-tungsten high-speed steel, chromium plated 1·2%-chromium tool steel and sintered-carbide-tipped tools, to determine whether the chromium plating increased the tool life. The results showed an increase in the life of from two to five times. With chromium-plated tools the cutting temperature should not exceed 300–350° C., and the specific cutting force should not exceed 200–250 kg./sq. mm.—R. A. R.

Observations on Deformations in Machining Chips. A. Portevin and P. Bastien. (Académie des Sciences, Dec. 2, 1940 : Métaux, Corrosion, Usure, 1941, vol. 16, Mar.–Apr., pp. 30–31). In order to understand the mechanism of machining of metals, longitudinal, horizontal, and vertical sections of metal chips were examined by micrographic, macrographic, micromechanic, and spectrographic methods and the deformation lines studied.—J. C. R.

High Speed Steels. (Echo des Mines, 1947, Apr., pp. 61–62). The cutting aspects of high-speed steels are reviewed.—R. F. F.

CLEANING AND PICKLING

Effect of Composition, Heat Treatment, and Cold Work on the Hydrogen Embrittlement of Stainless Steel Wire during Cathodic Pickling. C. A. Zapffe and O. G. Specht, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 193–211). This paper reports an extension of previous work on hydrogen embrittlement (*see* Journ. I. and S.I., 1946, No. I, p. 82A). The embrittlement of wires of steels 440-C (Cr 17%, C 1·0%),

410 (Cr 12%), and 431 (Cr 16%, Ni 2%) in the annealed, annealed and cold-drawn, and hardened conditions. Steels 410 and 431 were extremely susceptible to hydrogen embrittlement in the hardened condition, but were virtually immune when annealed. Graphs of the experimental results show the relative suceptibilities of these steels with equal concentrations of hydrogen at the surface, the effects of heat-treatment and cold-work, and the general progress of embrittlement with increasing time in the presence of hydrogen.—R. A. R.

Acid Composition, Concentration, Temperature, and Pickling Time as Factors in the Hydrogen Embrittlement of Mild Steel and Stainless Steel Wire. C. A. Zapffe and M. Eleanor Haslem. (Transactions of American Society for Metals, 1947, vol. 39, pp. 213–236). This report covers another stage in the investigation of hydrogen embrittlement (*see* preceeding abstract). It specifically concerns the following variables in acid pickling without the addition of inhibitors, namely, the composition, heat-treatment, and mechanical treatment of the steel, the composition, concentration, and temperature of the acid, and the pickling time. The acids studied were H_2SO_4, HCl, H_3PO_4, CH_3, COOH, HF, and HNO_3. Master graphs are developed which reveal the relationships of the seven variables.—R. A. R.

De-Rusting by Electrolytic Action. (Overseas Engineer, 1947, vol. 21, Nov., pp. 112–113). A general account is given of a method for removing rust from metal by electrolysis in an alkaline bath.—C. O.

Scale Removal. (Journal of the Birmingham Metallurgical Society, 1947, vol. 27, Sept., pp. 354–377). In an open discussion on scale removal the subject in general is reviewed by E. Bucknall, and mechanical scale-removal methods and the Dupont sodium hydride process are outlined by B. Thomas and Evans, respectively. —J. R.

Bright Annealing Replaces Pickling in Porcelain Enameling Plant. A. R. Mallon. (Iron Age, 1947, vol. 160, Nov. 6, p. 91). This article is an abstract of a paper which was presented at the Ninth Annual Porcelain Enamel Institute Forum. The cleaning of metal before enamelling by heating in a controlled reducing atmosphere at a temperature high enough to burn off all foreign matter is described.—C. O.

Oxide Conditioning Speeds Pickling Operations. C. B. Murton, jun., and M. F. Hawkes. (Iron Age, 1947, vol. 160, Oct. 30, pp. 46–48). The effect of the oxide structure on the pickling of steel and the cooling conditions necessary for obtaining the structure most favourable for rapid pickling are discussed.—C. O.

Influence of Pickling and Forming on the Wasters in Pressing Operations. B. Otta. (Hutnické Listy, 1946, vol. 1, No. 4, pp. 73–77). [In Czech]. Tests proved that greater care in the pickling process reduced the number of wasters in subsequent pressing by up to 10%, and that, in pack rolling, the sheet in contact with the bottom roll produced more wasters than the others.—R. A. R.

Treatment of Spent Pickling Liquors Containing Sulphuric Acid and Iron Sulfate. (British Intelligence Objectives Sub-Committee, 1947 ; F.I.A.T. Final Report No. 1117 : H.M. Stationery Office).

The Cleaning and Polishing of Small Parts in Drums and Bells. H. Krause. (Metalloberfläche, 1947, vol. 1, Feb., pp. 35–38 ; July, pp. 169–171). Equipment for the cleaning of small parts by tumbling in drums and open-ended vessels is described.—R. A. R.

Electropolishing with Fluosulfonic Acid. C. B. F. Young and K. R. Hesse. (Metal Finishing, 1947, vol. 45, Feb., pp. 63–67, 84 ; Mar., pp. 64–67). A number of solutions containing fluosulphonic acid were used for electrolytically polishing metals and alloys and the optimum operating conditions were established. Two solutions could be used for stainless steel: (*a*) Fluosulphonic acid 5–10%, and phosphoric acid 90–95% ; and (*b*) fluosulphonic acid 5–20%, phosphoric acid 60–90%, and up to 27% of 0·6–15% chromic oxide. Solutions of fluosulphonic acid, sulphuric acid, and water would not polish stainless steel. Fluosulphonic acid 5–10% with phosphoric acid 90–95% could be used for plain carbon steel.—R. A. R.

Some Special Applications of the Electrolytic Polishing of Metals. H. C. J. de Decker, A. P. Krijff, and J. M. Pluut, (Electrodepositors' Technical Society, 1947, vol. 24, Nov., pp. 2235–2241, 2242). Methods for the electrolytic polishing of carbon steels, zinc alloys, and lead alloys are described. The use of electrolytic polishing to obtain information about the mechanism of mechanical polishing of zinc surfaces is indicated. —C. O.

Electrolytic Polishing. J. Fischer. (Metalloberfläche, 1947, vol. 1, Apr. pp. 81–83). The advantages and disadvantages of electrolytic polishing are discussed and a table is presented which shows the techniques for carbon steel, stainless steel, and non-ferrous metals together with references to the literature.—R. A. R.

Sand-Blasting Metal Surfaces. F. Wehrmann. (Metalloberfläche, 1947, vol. 1, Mar., pp. 56–57). The equipment for sand-blasting is described with data on nozzle size, air quantity, air pressure, and sand consumption. —R. A R.

Shot-Blasting—A New and Valuable Process for Improving the Surfaces of Metals. F. Schröder. (Metalloberfläche, 1947, vol. 1, Apr., p. 87).

Processes for Removing Copper and Brass Coatings from Scrap Iron. C. Schaarwächter. (Metalloberfläche, 1947, vol. 1, Apr., pp. 89–90). Processes for removing copper, zinc, and brass coatings from iron and steel scrap are described.—R. A. R.

Superfinishing. (Métallurgie, 1947, vol. 79, May, pp. 15–16). This is a general account of the technique and applications of the superfinishing process.—J. C. R.

PROTECTIVE COATINGS

Measuring the Throwing Power of Plating Baths. (Metalloberfläche, 1947, vol. 1, Apr., p 77). Methods of measuring, and giving a numerical value for, the throwing power of plating baths are described.—R. A. R.

Metal Rectifiers. W. A. Flint. (British Engineering Export Journal, 1947, vol. 30, Nov., pp. 682–686). The Westalite selenium-compound rectifier has superseded the copper-oxide rectifier for the power supply of electroplating plants. The author enumerates the essentials of power-supply equipment for plating, and discusses the efficiency, upkeep, and maintenance of several types of Westalite rectifiers. The need for automatic control in repetition plating to specification and in anodizing is pointed out.—R. E.

Plating Bath Voltage. G. W. Croninger and J. B. Mohler. (Iron Age, 1947, vol. 160, Oct. 30, pp. 66–68). Data are given for the resistivity of a number of common electroplating solutions, and the use of these data for calculating the bath voltage, particularly with high current density, is explained.—C. O.

Electroplating Control Laboratory. H. J. Sedusky and J. B. Mohler. (Metal Finishing, 1947, vol. 45, Sept., pp. 60–63 ; Oct., pp. 68–71, 74). The various items of equipment used in a laboratory for the analysis and control of electroplating solutions are discussed in turn.—C. O.

Fluid Mechanics: Forgotten Factors in Electroplating. J. B. Kushner. (Metal Finishing, 1947, vol. 45, Oct., pp. 72–74). The author advocates the study of

hydrostatics in relation to electroplating processes. The advantages which, theoretically, should result from plating under pressure are indicated.—C. O.

Expedients for Making Waste Liquors Containing Chromic Acid Non-Toxic. F. Meinck. (Metalloberfläche, 1947, vol. 1, May, pp. 105–106). Methods of making non-toxic the waste liquor from chromium-plating plants are described.—R. A. R.

Toxicity of Chemicals in Electroplating. P. M. Van Arsdell. (Metal Finishing, 1947, vol. 45, Aug., pp. 55–67; Sept., pp. 79–83; Oct., pp. 75–81). Details are given of the toxic effects of each of the metals, salts, and other chemical compounds used in electroplating processes.—C. O.

Clad Steels. (Materials and Methods, 1947, vol. 26, Sept., pp. 97–108). A comprehensive account is given of the manufacture and application of clad steels, under the following headings: Cladding and backing materials; fabricating clad steels; heat-treating, cleaning, and finishing; and applications.—C. O.

A Survey of German Electro-Plating Methods. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1009: H.M. Stationery Office). A report is made on the equipment and methods used in Germany for electropolishing and electroplating. It is concluded that the German industry is as much as 12–15 years behind the British in development and technique.—C. O.

Electroplating Control Laboratory. H. J. Sedusky and J. B. Mohler. (Metal Finishing, 1947, vol. 45, Sept., pp. 60–63, Oct., pp. 68–71, 74). The factors to be considered in the choice of each of the pieces of apparatus necessary for the control of electroplating solutions are discussed.—C. O.

Periodic Reverse Current Electroplating. G. W. Jernstedt. (Steel Processing, 1947, vol. 33, Aug., pp. 479–482, 498: Metal Finishing, 1947, vol. 45, Feb., pp. 68–72). *See* Journ I. and S.I., 1947, vol. 157, Sept., p. 150.

Measurement of Embrittlement during Chromium and Cadmium Electroplating and the Nature of Recovery of Plated Articles. C. A. Zapffe and M. Eleanor Haslem. (Transactions of American Society for Metals, 1947, vol. 39, pp. 241–258). *See* Journ. I. and S.I., 1947, vol. 155, Jan., p. 154.—R. A. R.

Dropping Tests for Measuring the Thickness of Zinc and Cadmium Coatings. M. Ballay and J. Guinguené. (Revue de Métallurgie, 1945, vol. 42, Jan., pp. 15–21). The authors discuss the accuracy of Brenner's dropping test, by which the thickness of zinc and cadmium coatings on steel is determined.—R. A. R.

Reconstruction Work in Electroplating Shops. R. Erdmann. (Metalloberfläche, 1947, vol. 1, Jan., pp. 11–13; Feb., pp. 42–45).

Experience with Electrolytically Produced Bearing Surfaces on Plain Bearings with Special Regard to Foreign Countries. F. Bollenrath. (Metalloberfläche, 1947, vol. 1, Jan., pp. 3–10). The reasons for the development of bearings with the bearing surface produced by electrolytic deposition are explained. The methods of production are described, and examples of the results obtained with these bearings are given.—R. A. R.

The Electrolytic Deposition of Bright Metal Coatings. J. Fischer. (Metalloberfläche, 1947, vol. 1, Feb., pp. 28–31; Mar., pp. 49–56). The principles of electroplating are explained and descriptions are given of bright-plating processes for nickel, silver, cadmium, zinc, and copper.—R. A. R.

Production Line Rustproofing. A. D. Stout, jun. (Iron Age, 1947, vol. 160, Oct. 30, pp. 64–65). Methods employed by the Newark Stove Company, Newark, Ohio, for rust-proofing steel parts for electric cookers, on a mass-production basis are briefly outlined.—C. O.

The Electrochemical Investigation of Metals Protected by Basic Coatings. V. Cupr. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 264–267). Methods of determining the corrosion-resistance value of basic coatings and establishing a scale of such values are described.—R. A. R.

The Removal of Nitrates from Plating Baths, Especially from Nickel Baths. R. Wommelsdorf. (Metalloberfläche, 1947, vol. 1, July, pp. 164–165). A method for removing nitrate from nickel-plating baths is described.—R. A. R.

The Relative Merits of Electrodeposited Nickel and Chromium. R. E. Wilson. (Journal of the Institution of Production Engineers, 1947, vol. 26, Sept., pp. 329–348). An analysis is made of the respective merits of nickel and chromium electrodeposits. The importance of perfect adhesion is pointed out and the superiority of nickel in combating fretting-corrosion and in resisting corrosion-fatigue is emphasized. The effect of high temperatures on the two metals is discussed and it is shown that chromium is much harder than nickel and superior as a bearing material owing to its quality of slipperiness. The effects of pits, sharp edges and angles are shown and the advantage of large radii is stressed. The thickness of nickel deposits is dependent on commercial considerations, while comparatively thin deposits (not greater than 0·004 in.) are recommended.—R. E.

Coordination Compounds in the Electrodeposition of Chromium. R. W. Parry, S. Swann, jun., and J. C. Bailar, jun. (Electrochemical Society, 1947, Preprint 92-27). A detailed account is given of a study of the electrodeposition of chromium from solutions containing complex ions. It was found that chromic sulphate solutions are superior to chloride solutions as plating baths, and that no plating can be obtained in chromic nitrate or perchlorate solutions. No difference was found between the behaviour of the green and violet forms of chromic chloride. The presence of chromous ions in the bath is considered to be of fundamental importance.—C. O.

The Life of Chromium-Plating Baths Containing Silicon Fluoride. K. Gebauer and K. Sommer. (Metalloberfläche, 1947, vol. 1, Feb., pp. 25–27). Laboratory and full-scale tests were made to determine the life, under different conditions, of chromium-plating baths containing silicon fluoride. Laboratory tests using SiF_6''/SO_4'' chromium baths at current consumptions up to 12,500 amp.-hr./litre indicated that the life was practically indefinite. Full-scale tests with a 12,000-litre bath and a current consumption of 3350 ampere-hours/litre confirmed this, even when the bath was contaminated with 7 g. of iron per litre.—R. A. R.

Protection Against Corrosion by Chromium Impregnation. F. Steinberg. (Metalloberfläche, 1947, vol. 1, Mar., pp. 58–60). A description is given of a "chromizing" process in which the parts to be impregnated are heated for some hours at about 1000° C. in a gas mixture which forms chromium chloride vapour; a reaction then takes place in which iron chloride and chromium are formed. The properties and depth of the impregnated layer are discussed.—R. A. R.

Practical Methods in Heavy Industrial Nickel Plating. E. J. Roehl. (Metal Finishing, 1947, vol. 45, May, pp. 56–59, 71). The technique of electroplating steel and cast iron with thick deposits of nickel is outlined.—C. O.

The Precipitation of Hard Zinc in Hot-Dip Galvanizing. E. R. Thews. (Metalloberfläche, 1947, vol. 1, Feb., pp. 39–42; Mar., pp. 61–63; Apr., pp. 84–86). The causes of the formation of hard zinc during the hot-dip galvanizing process are discussed under the following headings: (1) Effect of the degree of purity of the zinc

and iron and of the preliminary treatment of the material to be coated ; (2) effect of the immersion time and bath temperature ; and (3) effect of the design of the kettle and the method of heating it.—R. A. R.

Practical Considerations on Hot Galvanizing. A. Gordet. (Métallurgie, 1947, vol. 79, Feb., pp. 21–22). Brief details are given of some practical aspects of pickling and hot-dip galvanizing.—J. C. R.

Chemical Treatments for Zinc Surfaces—A Review. H. A. Holden. (Electrodepositors' Technical Society : Sheet Metal Industries, 1947, vol. 24, Oct., pp. 1975–1983). A detailed review is made of the literature on the chemical treatment of zinc surfaces to increase their corrosion resistance or to prepare them for painting. —C. O.

A Protective Filming Process for Tinplate. H. R. Clauser. (Materials and Methods, 1947, vol. 26, Aug., pp. 97–100). An account is given of the Protectatin process for the formation on tinplate of a thin, invisible oxide film. The tinplate is dipped into a hot alkaline phosphate-chromate solution containing a suitable wetting reagent. The resulting film gives protection against sulphur staining and rusting in moist air, and provides a good base for paint.—C. O.

Protective Metallic Coatings from Molten Salts. H. R. Hoge. (Metal Progress, 1947, vol. 52, Nov., pp. 819–823). A general account is given of a method of applying a protective tin coating less than 0·001 in. thick to small steel articles by immersing them in a bath of molten tin chloride (either pure or diluted with other chlorides).—C. O.

The Determination of Tin Coating Weights on Tinplate. H. A. McKenzie. (Journal of the Society of Chemical Industry, 1947, vol. 66, Sept., pp. 312–319). An experimental comparison of chemical methods for estimating the weight of coatings on tinplate is reported. Hydrochloric acid inhibited with antimony trichloride was found to be the only reagent which completely removed the tin coating and the alloy layer from hot-dipped plates. The reagent and alkaline potassium iodate are recommended for electrolytic-plate determinations.—C.O.

Protecting the Surface of Steel by Copper Plating. H. Brōking. (Metalloberfläche, 1947, vol. 1, May, pp. 101–104). The production of copper-plated steel sheets by placing a copper sheet on a steel billet and pressing them between rolls in a protective atmosphere and at about 950° C. is described. Data on the adhesion of the copper and the corrosion resistance are given.—R.A. R.

Copper Plating—Cyanide-Free Electrolyte for Coppering Steel. A. Levin. (Zhurnal Prikladnoy Khimii, 1941, vol. 14, No. 1, pp. 74–78 : Electroplating, 1947, vol. 1, Nov., pp. 25–27). The results of investigations of the use of copper sulphate-oxalate solutions for the copper-plating of steel are presented. Alkaline copper-sulphate/ammonium-oxalate solutions were found to compare favourably with cyanide solutions.—C. O.

Copper–Titanium Alloy Coatings on Mild Steel. E. J. Chapin and C. R. Hayward. (Transactions of American Society for Metals, 1947, vol. 38, pp. 909–956). Copper–titanium coatings have been produced experimentally on steel plates by the following methods : (*a*) Heating copper-plated steel covered with a thin layer of powdered titanium hydride at 900° C. in a pure hydrogen atmosphere; (*b*) heating copper-plated or unplated steel covered with intimate mixtures of copper powder and powdered titanium hydride; and (*c*) melting a powdered precast 28/72 titanium–copper alloy on copper-plated or unplated steel. The results of metallographic examinations and hardness, bend, and corrosion tests on these coatings are presented. Copper–titanium alloy coatings of approximately eutectic composition (25% titanium) were found to have very interesting properties, including a high silvery lustre, a dense texture, and exceptional hardness.—C. O.

Lead Coatings *versus* Galvanizing. (Echo des Mines, 1946, Oct., p. 158). Lead coatings are compared with galvanizing for the protection of iron against corrosion. —R. F. F.

Lead Coatings for Steel Cables. (Echo des Mines, 1946, Nov., p. 172). The advantages of using lead for the protection of steel cables, in preference to galvanizing are discussed.—R. F. F.

Blistering of Cadmium Plate on Soldered Steel. E. R. Bowerman. (American Electroplaters' Society Monthly Review, 1947, vol. 34, Sept., pp. 1026–1031). Blistering of electro-deposited coatings has generally been attributed to faulty plating techniques, but another cause of blistering, namely, alloy formation between the electrodeposited metal and the base metal, is discussed with special reference to cadmium-coated soldered steel.—J. R.

Chemical Finishing of Metals. F. P. Heard. (American Electroplaters' Society Monthly Review, 1947, vol. 34, Sept., pp. 1035–1042). The application of oxide and phosphate coatings to ferrous and non-ferrous metals and alloys is discussed.—J. R.

Chromate Passivation of Sprayed Zinc Coatings. E. E. Halls. (Metal Treatment, 1947, vol. 14, Autumn Issue, pp. 164–168). The results of tests of the corrosion resistance of chromate-passivated sprayed-zinc coatings on steel are presented. The use of passivation in chromate solutions is considered to be justified when bare surfaces which do not corrode to give white products are essential, as where electrical contact is required.—C. O.

New Bonderizing Process for Aluminium and Steel. H. A. Knight. (Materials and Methods, 1947, vol. 26, Oct., pp. 99–101). A brief account is given of a slightly modified Bonderizing process suitable for the phosphate-coating of steel, aluminium, and zinc.—C. O.

Suppression of Radiations at High Temperatures by Means of Ceramic Coatings. D. G. Bennett. (Journal of the American Ceramic Society, 1947, vol. 30, Oct., pp. 297–305). A method was developed for measuring the emissivities of ceramic coatings and ceramic-coating materials with respect to oxidized stainless steel. The emissivities in the visible-red and near-infrared spectral regions were studied over a temperature range of 800° to 1600° F. The numerous materials investigated were found to cover an emissivity range from more than 100% to less than 10%. Lepidolite was the highest emitter, Uverite the lowest. Transmission of radiant energy decreased with coat thickness according to established laws. The transmission of radiant energy through coat-bonding glasses could be greatly influenced by composition. Every material has a characteristic tendency to emit radiation at a given temperature. High-temperature ceramic paints were found to be effective radiation suppressors and thermal insulators.

A Study of Dry-Process Cast Iron Ground-Coat Enamels. R. R. Danielson and J. H. Koenig. (Journal of the American Ceramic Society, 1947, vol. 30, Oct., pp. 306–311). Various firing treatments for ground-coat enamels on cast iron and their effect on the adherence and blistering tendency of dry-process enamels were investigated. Five ground-coats, composed of one and two frits with different clay and flint additions at the mill were used. Ordinary commercial ground coats must be fired so that the casting does not reach a given critical temperature which is about 1685° F. The firing range of ground-coats containing very fusible frits can be improved by moderate increase of the alumina at the expense of silica.—R. A. R.

Effect of Composition on Properties of Titanium Enamels. A. L. Friedberg, F. A. Petersen, and A. I. Andrews. (Journal of the American Ceramic Society, 1947, vol. 30, Sept. 1, pp. 261–277). The development of a super-opaque acid-resistant titanium enamel is described.—C. O.

Factors Affecting Chippage of Porcelain Enamel on Sheet Iron. E. E. Bryant. (American Ceramic Society Bulletin, 1947, vol. 26, Oct. 15, pp. 300–303). A chart is developed as a method of noting and studying the correlation of factors affecting the chipping of porcelain enamel coatings on sheet iron.—R. A. R.

Vitreous Enamelling on Holloware. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1440 : H.M. Stationery Office). A report is made on the vitreous-enamelling, galvanizing, and tinning practices of the German holloware industry.—C. O.

Developments in Peelable Plastic Coatings. T. D. McGuire. (Pressed Metal Institute : Steel Processing, 1947, vol. 33, Aug., pp. 487–488, 490, 508). A general account is given of the peacetime applications of "Liquid Envelope"—a plastic coating developed during the war for the protection of metals against corrosion. The coating, which may be peeled off after use, acts as a lubricant during the pressing of metals and protects the metal surfaces from die marks and abrasion.—C. O.

Rust Preventive Compounds. H. B. Carpenter. (Iron and Steel Engineer, 1947, vol. 24, Sept., pp. 73–78). An account is given of the use of two types of rust-preventive compounds—the non-hard-drying removable, petroleum-base and the hard-drying lacquer types.—C. O.

The Production of Heat-Resisting Metal Parts by Special Surface Treatment. A. Kufferath. (Metalloberfläche, 1947, vol. 1, July, pp. 171–173). The literature and patents on methods of coating or impregnating metal surfaces with aluminium are reviewed.—R. A. R.

Electrolytic Phosphatizing. R. Springer. (Metalloberfläche, 1947, vol. 1, Apr., pp. 78–80). The patent literature on processes of cathodic phosphatizing and phosphatizing with alternating current is reviewed.—R. A. R.

The Protection and Improvement of Large Metal Surfaces by Lacquers and Chemical Pickling. F. Zimmer. (Metalloberfläche, 1947, vol. 1, Apr., pp. 88–89). The coating of large metal surfaces in lacquering machines is described.—R. A. R.

Dust Prevention in Paint and Varnish Shops. A. Kufferath. (Metalloberfläche, 1947, vol. 1, Feb., pp. 32–34).

A Survey of Modern Methods for the Application of Paint to Metallic Surfaces. J. N. T. Adcock. (Sheet Metal Industries, 1947, vol. 24, Nov., pp. 2227–2232). Industrial methods of preparing metal surfaces for painting, applying paints to metals, and stoving paint films are reviewed.—C. O.

American Anti-Corrosive and Anti-Fouling Paints. (Engineer, 1947, vol. 184, Nov. 21, pp. 474–476). A very general account is given of the development of anti-corrosive and anti-fouling paints by the United States Navy since 1932, and of the methods used for painting ships at the New York Naval Shipyard.—C. O.

Service Tests of Experimental Anti-Fouling Compositions. H. Barnes, M. W. H. Bishop, and K. A. Pyefinch. (Journal of The Iron and Steel Institute, 1947, vol. 157, Nov., pp. 429–446). An account is given of a number of service tests in which experimental anti-fouling compositions were subjected to varying conditions of service. The results are analysed, taking into account the poison content of the compositions, the season over which the test was made, the route of the vessel, and periods in port. When all these factors are considered it may be possible to assess, with some degree of accuracy, the true performance of a composition ; however, under certain circumstances, this cannot be deduced. Examples are given of the way in which the results may lead to erroneous conclusions regarding the true value of the compositions used. On the other hand, even in the absence of severe fouling, a critical examination of the settlements on the test areas, when compared with those on non-toxic patches, together with a knowledge of the factors detailed above, can give reliable information of performance. This selection of small-scale service tests indicates their scope and value and suggests that further work of this type would be profitable.

Painting Exterior Steel Surfaces. R. Mansell. (Corrosion and Material Protection, 1947, vol. 4, Sept.-Oct., pp. 8–12). The author discusses the preparation of steel surfaces for painting, the relative merits of the brush and the spray for applying paint, the composition of paints for outdoor exposures, and the testing of the corrosion resistance of paint coatings.—C. O.

POWDER METALLURGY

Impact of Industrial Revolution on Powder Metallurgy. J. E. Drapeau, jun. (Metal Progress, 1947, vol. 52, Oct., pp. 606–608). A short account is given of the advantages which powder metallurgy possesses over conventional casting and machining processes, and of the development of the powder-metal industry in America since 1916. The author considers that powder metallurgy will maintain or extend its place in American economy as long as mass-production methods remain in use.—C. O.

Packing of Material in Bulk. D. R. Hudson. (Machinery, 1947, vol. 70, June 12, pp. 617–622 ; June 26, pp. 681–683). Various aspects of packing are considered, including packing densities for spheres and polyhedral materials, contacts in irregular materials and the mechanism of density improvement by shaking. The study of the mechanism of packing is of importance in the field of powder metallurgy.—R. E.

Pressed and Sintered Iron Powders. W. Rostoker. (Canadian Mining and Metallurgical Bulletin, 1947, vol. 50, Sept., pp. 497–508). Experiments on the effect of particle-size ratio on the packing density of commercial iron powders are reported. Only with mixtures of two or three sizes of particle was packing of a significant density obtained ; with more than three sizes of particles the packed densities were not very sensitive to composition. Further experiments were carried out to determine the effect of high packing density on the physical properties of pressed and sintered powders. It is concluded that the influence of particle packing on resultant physical properties is negligible.—C. O.

Powder Metallurgy. R. Girschig. (Revue de Métallurgie, 1945, vol. 42, June, pp. 178–186 ; July, pp. 218–229). The industrial applications of powder metallurgy are discussed. Pressing, sintering and some industrial applications of the products are described.—R. F. F.

Sintered Iron Shell Rotating Bands. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 979 : H.M. Stationery Office). This is a report on German methods of making shell rotating bands by powder metallurgy.—R. A. R.

The Losses in Carbon, Sulfur and Oxygen During the Sintering of Iron Powders in a Hydrogen Atmosphere. G. F. Hüttig and K. Sedlatschek. (Powder Metallurgy Bulletin, 1947, vol. 2, Sept., pp. 80–84). An account is given of experiments made to determine the losses of carbon, sulphur, and oxygen during the sintering

in hydrogen of 2 g. samples of loose and compacted mixtures of low-carbon-iron and cast-iron powders. Under the conditions of the experiments only small differences were found between the temperature/percentage-loss curves for the pressed and unpressed powders. The sulphur contents of both powders and compacts began to decrease at temperatures slightly below 600° C., but in the presence of additions of ferrous chloride these temperatures could be reduced by about 300° C. The results indicate that the oxygen content of powders and compacts can be reduced without appreciably affecting the carbon content by heating at temperatures below 500° C.—C. O.

Formation and Transformation Studies of Iron–Carbon Powder Alloys. J. F. Kahles. (Transactions of American Society for Metals, 1946, vol. 38, pp. 618–658). *See* Journ. I. and S. I., 1947, vol. 155, Jan., p. 155.

PROPERTIES AND TESTS

The Significance of Mechanical Testing. H. E. Davies and J. McKeown. (Midland Metallurgical Societies: Metallurgia, 1947, vol. 37, Nov., pp. 19–22). In the opening remarks at a discussion of the significance of mechanical testing H. E. Davies dealt mainly with ductility and Izod impact tests, whilst J. McKeown discussed the effect of temperature on fatigue resistance.—R. A. R.

Reducing Failures in Metal Parts. A. E. Focke. (Mining and Metallurgy, 1947, vol. 28, Oct., pp. 495–497). Ways in which the metallurgist can utilize his knowledge of the behaviour of metals to improve engineering design are indicated.—C. O.

Industrial Applications of Statistics. P. Ferignac. (Revue de Métallurgie, 1945, vol. 42, Nov., pp. 359–367). Industrial applications of statistics, as exemplified, in particular, by the study of the properties of steels, are reviewed.—R. F. F.

Basic Physical Properties Relied upon in the Frozen Stress Technique. W. A. P. Fisher. (Institution of Mechanical Engineers, 1947, Preprint). The physical properties of "Glyptal" resin and the glass-clear phenol-formaldehyde resin "Catalin 800" which make these materials suitable for the determination of stresses by the photo-elastic "frozen stress" technique are compared. Experimental results obtained with Catalin 800 are presented as an illustration.—C. O.

Modern Applications of Photo-Elasticity. R. B. Heywood. (Institution of Mechanical Engineers, 1947, Preprint). A general account is given of the use of photo-elasticity for the analysis of stresses in engineering parts. Two- and three-dimensional techniques are explained, with examples of their applications.—C. O.

Contribution to the Theory of the Plasticity of Metals and Alloys. P. Laurent. (Revue de Métallurgie, Mémoires, 1945, vol. 42, Mar., pp. 79–92; Apr., pp. 125–132; May, pp. 156–167; June, pp. 194–202; July, pp. 230–239). The author critically reviews the existing theories explaining the plasticity of crystals, and advances his own theory. The paper is divided into the following chapters: I—Crystalline plasticity. II—Theories of crystal plasticity. III—A new theory of crystal plasticity. IV—An investigation of the critical shear stress. V.—Atomic strain hardening. VI—Deformation curves at constant rate. VII—Investigations of creep under constant stress. VIII—Recovery at constant temperature. IX—Dynamic strain hardening: Strain hardening of alloys. X—Fracture of perfect crystals by slip. XI—The deformation of polycrystalline materials. XII—Subpermanent deformation. (An English translation has been prepared, *see* next abstract).—R. A. R.

Contribution to the Theory of the Plasticity of Metals and Alloys. P. Laurent. (Iron and Steel Institute, 1947, Translation Series, No. 328). This is an English translation of a paper which appeared in Revue de Métallurgie, Mémoires, March–July, 1945 (*see* preceding abstract).—R. A. R.

The Calculation of the Increase in Strength Due to Stress in Cold Extension and Cold Heading. H. Brandenberger. (Schweizer Archiv, 1947, vol. 13, Aug., pp. 232–238; Sept., pp. 268–275). When a notched specimen is stressed in tension at above the elastic limit plastic deformation occurs where the stresses are concentrated and, when the load is removed, there is a residual stress in the opposite direction. This residual stress increases the capacity of the material to resist external tensile stresses. The question arises whether residual stresses can be built up in unnotched bars by cold deformation in simple tension or compression, which would increase the capacity to carry loads applied in the opposing direction, *i.e.*, raise the elastic limit. To achieve this it is necessary to produce internal deformation in addition to the load which is equally distributed over the section. This internal deformation is produced, for example, by precipitation hardening when the internal grains of a bar undergo a volume change. The author uses data on the forces causing changes in volume and shape, and space and lattice stress values to calculate the increase in strength produced by cold extension and cold heading.—R. A. R.

Percentage Elongation of Steel. A. C. Vivian. (Journal of the Institution of Civil Engineers, 1947, vol. 29, Dec., pp. 138–153). The total elongation of a steel bar fractured by a tensile load consists of two distinct parts: (*a*) An approximately uniform extension, followed by (*b*) a necking to fracture. The purpose of this paper is to establish these principles firmly on the test measurements published by W. C. Unwin in 1903, and on others published by Blount, Kirkaldy, and Sankey in 1910, and then to demonstrate the quantitative data which users of steel can obtain from them.—R. A. R.

The Effect of Notching on Materials of Construction Under Static and Dynamic Tension. (Maximum Testing Velocity 29 feet/second). G. Welter. (Metallurgia, 1947, vol. 36, Sept., pp. 283–286; Oct., pp. 339–343; vol. 37, Nov., pp. 36–40). The results of static and dynamic tensile tests on notched and unnotched specimens of various ferrous and non-ferrous constructional materials are presented. Impact- and static-loading force-elongation diagrams were recorded on a specially designed device, which is described. It is considered that most materials can be classified into three groups according to their behaviour under impact-loads: (1) Materials which are brittle at low impact speeds whether the specimen is cylindrical or notched; (2) materials the strength and elongation of which increase with increasing speed when tested in the form of cylindrical specimens of at least ½-in. gauge length, but are sensitive to notching; (3) the very tough materials, such as nickel-iron and nickel-copper alloys, which flow locally at the bottom of notches even under high speeds of deformation.—C. O.

Important Considerations in Charpy and Izod Testing. C. M. Schwitter. (Product Engineering, 1947, vol. 18, Oct., pp. 106–109; Nov., pp. 159–162). The merits of the various types of standard Izod and Charpy test-pieces are compared and the conditions necessary for accurate testing are discussed.—C. O.

Changing the Stressed State at the Surface of Materials by Etching. F. Lihl. (Archiv für Metallkunde, 1946, vol. 1, Oct., pp. 16–25). The examination of several

hundred X-ray diagrams revealed that the etching of steels produced considerable surface stresses, called etch stresses, which were always compressive. The stresses were produced by either chemical or electrolytic attack. The magnitude of the stress depends upon the material, its heat-treatment, and (in electrolytic polishing) the current density; it does not depend on the acid used. The stresses can be removed by annealing. The only etching process which did not produce surface stresses of any importance was electrolytic etching in very dilute acid. A theory for the causes of etch stresses is advanced. This theory indicates that measurements of the lattice parameters of metals by gas absorption need revision because they do not take into account the fact that the gasification also causes surface stresses operating in the same direction as that in which the lattice is expanded by the absorption of gas, so that the true effect of the latter is less than that measured. —R. A. R.

Cohesion of Metals. Sir Lawrence Bragg. (Bulletin de la Société Française de Métallurgie, 1945, pp. 53–59 : Revue de Métallurgie, 1945, vol. 42, June, pp. 187–194). The internal cohesion of metals is discussed and the apparatus used to demonstrate the effects of internal stress by " rafts " of soap bubbles is described.—R. A. R.

The Effects of Microstructure on the Mechanical Properties of Steel. J. H. Holloman, L. D. Jaffe, D. E. McCarthy, and M. R. Norton. (Transactions of American Society for Metals, 1946, vol. 38, pp. 807–847). *See* Journ. I. and S.I., 1946, No. II, p. 137A.

How to Evaluate Engineering Properties of Iron Powder Parts. A. Squire. (Materials and Methods, 1947, vol. 25, June, pp. 89–93). The extent to which the values obtained in tests of the mechanical properties of iron-powder test-pieces may be taken as indicative of the performance of engineering components made from such powders is discussed. Data are given on the relationships between processing conditions and physical properties and the inter-relation of quality characteristics.—C. O.

Deformation of Metals during Single and Repeated Tensile Impact. J. A. Pope. (Journal of The Iron and Steel Institute, 1947, vol. 157, Sept., pp. 31–54). The main purpose of the research was to examine in some detail the process of deformation during single and repeated tensile impact. The falling-tup type of machine was used and an adjustable stop was fitted to the machine so that either a single impact could be split up into a number of stages or repeated impact tests could be carried out with constant velocity of deformation. The mode and spread of deformation was examined by microscopic examination, by Vickers hardness test, and by measuring the change in diameter of the specimen at various points. The metals subjected to these tests were Lowmoor iron and mild steel. A general theory expressed in dimensionless groups is developed in the early part of the paper to explain the mode of deformation. This gives good agreement with experimental results. It was found that the spread of deformation along the specimen during impact was fundamentally different from that for static deformation. Hardness tests taken along the centre and edge of deformed steel and iron specimens showed that the increase in hardness at the centre of the specimen was larger than that at the edge by a greater amount in impact than in static tests. Tests on brass specimens showed no such hardness variation. Finally it was found that impact-percentage-elongation/static-percentage-elongation is a function of the gauge length of the specimen and is not a fundamental property of the metal.

Fatigue Strength of Steel Parts. P. O. Johnson and C. Lipson. (Product Engineering, 1947, vol. 18, Oct., pp. 144–146). Charts are presented which show the relationships between the fatigue strength and the hardness, surface condition, and stress concentrations of steel parts.—C. O.

Tests to Determine the Depth of Hardening and the Tendency towards Grain Growth of Carbon Tool Steels. G. Rémy. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, Mar., pp. 287–314). Details are given of hardenability tests on 14 tool steels having two ranges of carbon content, from 0·78% to 0·95% and from 1·15% to 1·34%. The specimens were heated to temperatures in the range 790°–975° C. and quenched in a jet of 10% brine at 15° C. The results of the tests showing the depth of hardening and the grain growth are presented in tabular and graphical form. Other graphs show the effect of variation of the carbon content and the temperature to which the specimens were heated prior to quenching, on the depth of hardening and grain growth.—J. C. R.

A New Microhardness Tester—The " L.C. Microsclerometer." R. Girschig. (Iron and Steel Institute, 1947, Translation Series, No. 322). This is an English translation of a paper which appeared in Revue de Métallurgie. Mémoires, 1946, vol. 43, Mar.–Apr., pp. 95–112. It describes an instrument for testing the hardness of micrographic constituents; it can be used with the majority of metallographic microscopes.—R. A. R.

Determination of Knoop Hardness Numbers Independent of Load. L. P. Tarasov and N. W. Thibault. (Transactions of American Society for Metals, 1947, vol. 38, pp. 331–348). The authors show how a very precise Knoop hardness number, independent of the applied load, can be calculated for a given specimen from the lengths of the indentations made at several different loads. A constant length correction is found by trial and error which, when added to the measured indentation lengths gives approximately the same hardness number for each load. The hardness number is shown to be the unrecovered hardness number.—C. O.

Hardenability of Shallow Hardening Steels Determined by the P-V Test. B. F. Shepherd. (Transactions of American Society for Metals, 1947, vol. 38, pp. 354–385). The author describes a quenching test suitable for the determination of the hardenability of shallow-hardening steels which require cooling rates faster than 80° F./sec. at 1300° F. in order that the microstructure retains 50% of martensite. The specimen for this test, which is known as the P-V test (Penetration–Velocity or Penetration-**V** shape) is formed from a $1\frac{1}{4}$–$1\frac{3}{4}$-in. dia. round bar by making two mutually perpendicular cuts at 45° to the axis to give a chisel edge. The specimen is quenched in a special fixture by causing a jet of water to impinge on the chisel edge; it is sectioned parallel to the axis, hardness measurements being made on the cut faces.—C. O.

Study of the Weldability of Various Steels by Means of the Jominy Test and the Shepherd Test. R. Marchand and J. Arveux. (Bulletin du Cercle d'Études des Métaux, 1947, vol. 4, Sept., pp. 503–510). The Jominy and Shepherd tests for determining hardness penetration are described and their application in studying the weldability of various steels is reviewed.—J. C. R.

Generalization on the Detection of Brittleness in Steels. G. Vidal. (Comptes Rendus, 1947, vol. 224, Feb. 10, pp. 394–395). New tests, using a Charpy drop-hammer pendulum appliance, have confirmed that overheating and temper brittleness can be detected by an impact bend test at low temperatures on a polished unnotched test-piece. As a result of the tests the author concludes that, of the three factors involved in the detection of brittleness, neither the notch, the impact, nor the temperature, taken singly, is sufficient to ensure detection,

but the temperature plays a fundamental rôle.—J. C. R.

Brittle Fracture in Mild-Steel Plates. W. Barr and Constance F. Tipper. (Journal of The Iron and Steel Institute, 1947, vol. 157, Oct., pp. 223–246). The temperature range of transition from tough to brittle fracture of mild-steel plates of different carbon and manganese contents was determined by means of notched-bar impact, notched bend, and notched tensile tests. The results obtained by each of these tests were in good agreement, except that for very soft steels the notched tensile test gave a lower transition range than the other two tests. It was found that the transition range is raised by an increase in the ferritic grain-size, by an increase in plate thickness, and by slow cooling after normalizing. It was also found that a high notched-bar impact value may be accompanied by a fracture which is mainly cleavage. Tentative conclusions, subject to confirmation, have been reached that the effects of plate thickness and slow rates of cooling in raising the transition range are reduced in mild-steel plates with higher manganese contents.,

Effect of the Manganese/Carbon Ratio on the Brittle Fracture of Mild Steel. W. Barr and A. J. K. Honeyman. (Journal of The Iron and Steel Institute, 1947, vol. 157, Oct., pp. 239–242). A series of four mild steels was made in which the only significant variable was the manganese/carbon ratio. The residual elements were low and the tensile strengths were approximately the same for each steel. The notched-bar impact properties of these steels in the annealed and in the normalized conditions have been determined. It was found that increasing the manganese/carbon ratio lowers the range of transition from tough to brittle fracture, increases the impact values at all temperatures, and tends to result in finer McQuaid-Ehn and ferritic grain-sizes. A practical recommendation is made that for structural steels for shipbuilding purposes, the manganese/carbon ratio should be not less than 3·0.

Strain-Age Embrittlement of Steel. (Engineer, 1947, vol. 184, Oct. 31, pp. 412–413). Investigations of the strain-age embrittlement of steel are reviewed with special reference to the work of B.D. Enlund (*see* Iron and Steel Institute, Translation Series, No. 307) and of W. Bading (*see* Journ I. and S.I., 1947, vol. 157, Sept., p. 141).—R. A. R.

Development of Temper Brittleness in Alloy Steels. W. S. Pellini and B. R. Quenau. (Transactions of American Society for Metals, 1947, vol. 39, pp. 139–153). *See* Journ. I. and S.I., 1946, No. II, p. 138A.—R. A. R.

Temper-Brittleness. A. Michel. (Bulletin du Cercle d'Études des Métaux, 1945, vol. 4, June, pp. 213–232). The author reviews the work of various investigators on this subject in recent years. In the discussion L. Colombier gives an account of tests made with a chromium–molybdenum–nickel steel from which he concludes that there is a connection between temper-brittleness and primary segregations, and a similarity between the phenomena of temper-brittleness and overheating.—J. C. R.

Note on the Brittleness of Steels. H. Jolivet. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, Mar., pp. 315–324). An account is presented of the theory of the phenomena of brittleness in steels.—J. C. R.

Effect of the Conditions of Pouring and Rolling on the Incidence of Cracks in the Base of S49 Rails. W. Jäniche. (Stahl und Eisen, 1947, vol. 66–67, Aug. 14, pp. 284–290). An investigation is described in which the incidence of cracks and the resistance to bending of flat-bottomed rails S49 were related to the pouring conditions (whether top- or bottom-poured) and the rolling process. The test data are examined statistically and it is shown that there were fewer defects in rails from bottom-poured ingots.—R. A. R.

Relation of Quenching Rate and Hardenability to the Mechanical Properties of Several Heat-Treated Cast Alloy Steels. C. R. Wilks, H. S. Avery, and E. Cook. (Transactions of American Society for Metals, 1946, vol. 38, pp. 437–470). *See* Journ. I. and S.I., 1946, No. II, p. 138A.

The Measured Knoop Hardness of Hard Substances and Factors Affecting Its Determination. N. W. Thibault and H. L. Nyquist. (Transactions of American Society for Metals, 1946, vol. 38, pp. 271–353). *See* Journ. I. and S.I., 1946, No. II, p. 137A.

Hardness Testing of Metals and Alloys at Elevated Temperatures. F. P. Bens. (Transactions of American Society for Metals, 1946, vol. 38, pp. 505–516). *See* Journ. I. and S.I., 1946, No. II, p. 137A.

The Stress Rupture and Creep Properties of Heat Resistant Gas Turbine Alloys. N. J. Grant. (Transactions of American Society for Metals, 1947, vol. 39, pp. 281–334). *See* Journ. I. and S.I., 1946, No. II, p. 138A.

The Apparent Influence of Grain Size on the High Temperature Properties of Austenitic Steels. C. L. Clark and J. W. Freeman. (Transactions of American Society for Metals, 1946, vol. 38, pp. 148–179). *See* Journ. I. and S.I., 1946, No. II, p. 138A.

The Effect of Manganese on the Properties of Cast Carbon and Carbon–Molybdenum Steels. N. A. Ziegler, W. L. Meinhart, and J. R. Goldsmith. (Transactions of American Society for Metals, 1946, vol. 38, pp. 398–436). *See* Journ. I. and S.I., 1946, No. II, p. 139A).

Changes in Size and Toughness of High-Carbon High-Chromium Steels Due to Subzero Treatments. L. E. Gippert and G. M. Butler, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 549–568). *See* Journ. I. and S.I., 1946, No. II, p. 139A.

The Fluidity of Steel. R. Jackson, D. Knowles, T. H. Middleham, and R. J. Sarjant. (Journal of The Iron and Steel Institute, 1947, vol. 157, Sept., pp. 1–21). The paper describes experimental investigations on the fluidity/temperature relationships, as indicated by Ruff and spiral mould tests, of four steels, *viz.*, (1) 2% Cu steel, (2) Si–Ni steel, (3) low-carbon steel, and (4) 13% Mn steel, melted in high-frequency furnaces with acid and basic linings. Temperature measurements were made by optical and quick-immersion-couple methods. The spiral mould gave more consistent results than the Ruff. Comparison of the authors' results with those of Taylor, Rominski, and Briggs on similar steels showed widely differing fluidity/temperature relationships with similar moulds. Investigation of the pyrometric methods employed in the two sets of trials indicated that the differences could be mainly ascribed to the time lag in the temperature measurements employed by the American authors.

Iron-Loss Measurements by A.C. Bridge and Calorimeter. J. Greig and H. Kayser. (Institution of Electrical Engineers, 1947, Preprint). A description is given of a calorimeter designed for measuring the power loss in magnetic ring specimens under non-incremental audio-frequency excitation, with the object of checking results of measurements made by the Owen bridge under conditions involving appreciable non-linear distortion; reasons for the choice of the calorimetric method are outlined, and the use of the calorimeter as a transfer instrument is considered. The application of the Owen bridge for the measurement of iron losses is discussed, and results are given of measurements made on ring specimens built up of silicon-steel stampings of two different thicknesses, for values of flux density up to 10 kilogauss and of frequency up to 10 kilocycles.

X-Ray Inspection Promotes Casting Quality Control. E. H. Grimm. (Foundry, 1947, vol. 75, Oct., pp. 94–96, 130, 133, 136). Examples are described of the use of a 1,000,000-V. X-ray machine for testing castings such as automobile crankshafts and bases of lifting jacks.—R. A. R.

Heat Transmission from Fine Wires to Water. E. L. Piret, W. James, and M. Stacy. (Industrial and Engineering Chemistry, 1947, vol. 39, Sept., pp. 1098–1103). A description is given of hot-wire anemometer apparatus with which heat-transfer data were obtained at water velocities lower than previously reported, and over a relatively wide range of water temperatures.—R. A. R.

Non-Destructive Methods for Determining Metal Plate Thickness. J. G. Kerley. (Corrosion, 1947, vol. 3, Oct., pp. 467–481). Short accounts are given of the principles and operation of commercially available instruments for measuring the thickness of metal plates. Instruments using each of the following phenomena are described: Ultrasonic vibration, thermal conductivity, magnetism, electrical resistivity, electrical induction, and penetrating radiation.—C. O.

The Stress Rupture and Creep Properties of Heat Resistant Gas Turbine Alloys. N. J. Grant. (Transactions of American Society of Metals, 1947, vol. 39, pp. 281–325). *See* Journ. I. and S.I., 1946, No. II, p. 138A.—R. A. R.

Stability of Steels at Elevated Temperatures. A. B. Wilder and J. D. Tyson. (Steel, 1947, vol. 121, Oct. 20, pp. 86–89, 108–111). An outline is given of a large-scale investigation on the stability at high temperatures of various piping materials now being carried out by the National Tube Co., Pittsburgh. The structural and physical properties of some 60 different steels are being studied after exposures at high temperatures for periods of up to eleven years, in order to determine their graphitization characteristics and the effect on graphitization of welding, preliminary heat-treatment, etc.—C. O.

Cast Heat Resistant Alloys of the 16% Chromium 35% Nickel Type. H. S. Avery and N. A. Matthews. (Transactions of American Society for Metals, 1947, vol. 38, pp. 957–1015). The results of extensive tests of the physical and mechanical properties of cast alloys of the "*HT*" type (16% chromium, 35% nickel, remainder iron) are presented. Comparisons are made with the characteristics of the "*HH*" type alloys (26% chromium, 12% nickel, remainder iron).—C. O.

High Temperature Alloys. Development for Gas Turbines. Sir W. T. Griffiths. (Metal Industry, 1947, vol. 71, Oct. 31, pp. 359–362; Nov. 7, pp. 379–381; Nov. 14, pp. 401–403). The interpretation of creep curves and other test data is discussed from the point of view of assessing the value of a metal or alloy for high-temperature service. The special requirements of alloys for rotor blades, rotor discs, nozzle guide vanes, and combustion chambers are discussed, and the compositions and characteristics of some alloy steels and non-ferrous alloys are reviewed. The properties of "Nimonic 80" are given in some detail.—M. A. V.

Overheating and Burning and Their Correction. J. Vernay. (Bulletin du Cercle d'Études des Métaux, 1942, vol. 3, Mar., pp. 159–169). Details are given of fatigue and impact tests carried out on various chromium–molybdenum–nickel steels, which had been overheated, and the results obtained are tabulated.—J. C. R.

A Note on Optical Pyrometry. R. Weil. (Journal of The Iron and Steel Institute, 1947, vol. 157, Nov., pp. 415–416). The effect of the variation with temperature of emissivity is discussed, and it is shown that under certain circumstances it may be possible to express this variation in terms of changes of electrical resistivity also in the near infra-red and visible parts of the spectrum.

Contribution to the Study of the Behaviour of Heated Austenitic and Austenitic-Ferritic Steels of the 18/8 Type. J. Hochmann. (Bulletin du Cercle d'Études des Métaux, 1947, vol. 4, Sept., pp. 485–502). An account is given of tests on 18/8 steels, with carbon contents varying from 0·02% to 0·3%, to determine their behaviour between 550° and 800° C. The relation of the carbon content to creep resistance and the relation between intercrystalline corrosion and intercrystalline fracture are studied. Results are also presented of tests on a steel (C 0·2%, Si 1·5%, Mn 1·5%, Cr 19%, Ni 7%, W 4%) having a two-phase austenite-ferrite structure.—J. C. R.

Hydrogen Attack on Metals at High Temperatures and Pressures. J. Schuyten. (Corrosion and Material Protection, 1947, vol. 4, Sept.-Oct., pp. 13–18). A comprehensive survey is made of the published information on the effect of hydrogen on the properties of metals at high temperatures and pressures.—C. O.

On the Phenomena of Absorption and Evaporation Produced at the Surface of Iron after Acid or Electrolytic Pickling. P. Bastien, S. Mischonsniky, and Chantal de Senneville. (Comptes Rendus, 1947, vol. 224, Jan. 13, pp. 126–127). A 0·6% carbon basic open-hearth steel wire was annealed at 950° C. and then charged with hydrogen either by immersion for 48 hr. in a 10% hydrochloric acid solution or by electrolytic pickling for the same period. Specimens were dried and exposed to the atmosphere and their increase in weight noted. In a further experiment after pickling and exposing to the air for 2–6 hr. the wire was immersed in mercury in an apparatus attached to a gas analyser. The results showed a slight evolution of oxygen and nitrogen as well as a heavy evolution of hydrogen.—J. C. R.

Experiments on the Fusion of Graphite in High-Pressure Argon up to 11,500 Kg. per Sq. Cm. Determination of the Triple Point and Establishment of a Provisional Diagram for the Solid, Liquid and Gaseous Phases of Carbon. J. Basset. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 7–19).—R. F. F.

Relationship of "Flowering" to the Phenomena of Capillarity and Diffusion. E. Eyt. (Fonderie, 1946, Feb., pp. 53–61). The author has studied the formation of "flowers" on the surface of liquid iron and steel. In the first part he considers the time the skin takes to form, the temperature at which it forms, and its chemical and physical composition. Secondly he deals with the colour and mobility of the "flowers" which indicate the quality of the metal and its gas and oxide contents. Finally he refers to the relationship of "flowering" to diffusion, surface tension and viscosity.—J. C. R.

Present Day Special Steels. P. Montereau. (Métallurgie, 1947, vol. 79, Apr., pp. 11–12; May, pp. 13–14). An account is presented of war-time and post-war developments in high-speed, tool, stainless, magnet and structural steels in France.—J. C. R.

Postwar SAE Steels—Expanded Steel Specification Tables Reflect Current Automotive Practice. (SAE Journal, 1947, vol, 55, Nov., pp. 17–23). Details are given of changes in the SAE steel specifications of the 55 new steels added, 10 are in the 1000 carbon-steel series, 11 in the 1100 free-cutting-steel series, and 30 are alloy steels. Almost all of the 47 steels which have been deleted from the list are wartime N.E. steels.—C.O.

The Influence of Very Small Sulphur Inclusions on the Quality of Steel. L. Colombier. (Comptes Rendus, 1945, vol. 220, pp. 886–888: Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, June, pp. 341–343). Two ingots of chromium–molybdenum–nickel steel were cast and, after partial cooling, iron sulphide was added

to one of them, increasing the sulphur content from 0·007% to 0·012%. Tensile strength and elongation were found to be unaffected, but impact strength was perceptibly lowered by the addition of the sulphur. —J. C. R.

The Effect of Stress Relief Heat Treatment on the Technical Properties of Structural Steels and Structural Elements. O. Graf. (Stahlbau, 1944, vol. 17, pp. 65–68 : Welding Journal, 1947, vol. 27, Sept., pp. 517-s–518-s). A short summary is made of results obtained in tensile and bead-bend tests on H beams welded from ¾-in. steel plate. It was found that a stress-relief heat-treatment increased the tensile strength of such girders, and that stress-relieved specimens invariably gave a very large angle in the bead-bend test.—C. O.

The Effect of Changes in Condition of Carbides on Some Properties of Steel. J. B. Austin. (Campbell Memorial Lecture : Transactions of American Society for Metals, 1947, vol. 38, pp. 28–69). The author summarizes the experimental evidence for the existence of variation in the composition of cementite. It is shown that there is ample reason to believe that the carbon content of cementite in equilibrium with ferrite is sensibly constant at the stoichiometric ratio, whereas that of cementite in equilibrium with austenite decreases with increasing temperature. There is some indication also that carbon may be replaced in cementite by nitrogen and experimental data have confirmed predictions made from a study of the structure of cementite that the carbon may be replaced extensively by manganese and chromium, to a limited extent by molybdenum and tungsten, and very slightly by vanadium. For a given temperature and carbon content, the alloying element in the carbide increases linearly with the gross content of the element in the steel, and the partition coefficient is such that at equilibrium the alloying element tends to concentrate in the carbide.

The influence on variations in the composition of cementite, such as may be brought about by heat-treatments, on some properties of steels is illustrated by specific examples.—C. O.

Changes in Size and Toughness of High-Carbon High-Chromium Steels Due to Subzero Treatments. L. E. Gippert and G. M. Butler, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 549–557). *See* Journ. I. and S.I., 1946, No. II, p. 139A. —R. A. R.

Ingot Factors in the Production of Seamless Gun Tubes. J. W. Spretnak, K. L. Fetters, and E. L. Layland. (Transactions of American Society for Metals, 1947, vol. 39, pp. 627–650). The relation between factors relating to ingots and the occurrence of defects in the bore of thick-walled seamless gun tubes was studied. The frequent occurrence of defects in tubes made from the bottom third of ingots was noted.—R. A. R.

Pole Figures of the Effect of Some Cold-Rolling Mill Variables on Low Carbon Steel. J. K. Wood, jun. (Transactions of American Society for Metals, 1947, vol. 39, pp. 725–736). *See* Journ. I. and S.I., 1946, No. II, p. 137A.—R. A. R.

Mechanical Properties of Cast Low Alloy Steels. M. F. Hawkes. (Transactions of American Society for Metals, 1947, vol. 39, pp. 1–40). The hardenability, tensile and impact strengths, grain-size, and inclusion ratings of 32 cast alloy steels of the National Emergency type are presented and discussed. The similarity in the properties of cast and wrought alloy steels is shown. The advantages of quenching and tempering over normalizing and tempering are indicated. Cast N.E. alloy steels with properties comparing favourably with the older cast alloy steels and with wrought alloy steels can be readily produced.—R. A. R.

Stress Cracking of Electroplated Lockwashers. K. B. Valentine. (Transactions of American Society for Metals, 1947, vol. 88, pp. 488–494). An investigation of the effect of hardness on the failure of electroplated lockwashers is described. It was found that the lower the hardness, the smaller was the percentage of failures encountered, and that in washers with a hardness below Rockwell C-50, critical hydrogen embrittlement was eliminated by a thermal ageing treatment after plating.—C. O.

Nondestructive Inspection of Mine Hoist Cable. P. E. Cavanagh and R. S. Segsworth. (Transactions of American Society for Metals, 1947, vol. 38, pp. 517–545). The adaptation of the Cyclograph, a magnetic fault detector, to the non-destructive inspection of mine hoist rope is described. In preliminary experiments fundamental relationships were established between the magnetic and electrical properties and increases in stress in wire ropes. Tests under operating conditions showed that the relationships between the stresses in ropes and instrument readings remained valid at high hoisting speeds, and that testing did not interfere with the operation of the hoist.—C. O.

Non-Destructive Testing. A. M. Armour. (Iron and Steel, 1947, vol. 20, Nov., pp. 525–527). This paper has already been published under the title " A New Method of Non-Destructive Spot-Weld Testing for Stainless Steel." (*See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 649).—R. A. R.

The Cast Crankshaft. R. Bertschinger. (Iron and Coal Trades Review, 1947, vol. 155, Oct. 24, pp. 795–797). The improved materials and designs which have been reponsible for the increasing use of cast internal-combustion-engine crankshafts are surveyed.—C. O.

Cast Steels. C. W. Briggs. (American Society of Mechanical Engineers : American Foundryman, 1947, vol. 12, Sept., pp. 37–43 ; Oct., pp. 44–50). A comprehensive range of investigations, planned by the Steel Founders' Society, has been carried out on the properties of cast steels at the Carnegie Institute of Technology, the Case School of Applied Science, and the Michigan College of Mines and Technology. The results of many series of tests are given in this paper.—R. A. R.

Stainless and Carbon Steels Used in Cutlery. (Echo des Mines, 1947, Jan., pp. 10–11). Steels used in France for cutlery manufacture are described.—R. F. F.

Alloyed Substitute Structural Steels and Their Future Prospects. (Echo des Mines, 1946, Oct., pp. 157–158 ; Nov., pp. 174–175). The properties of substitute structural steels are reviewed.—R. F. F.

The Production and Application of High-Purity Metals. K. Giesen. (Technik, 1947, vol. 2, Sept., pp. 393–398). A review is presented of methods of producing very pure metals including lead, copper, nickel, zinc, aluminium, and iron. The influence of impurities on the properties of the metals and applications of the metals are discussed.—R. A. R.

Metals on Trial. (New Zealand Engineering, 1947, vol. 2, July 10, pp. 686–687). A survey is made of the types of testing undertaken by the Engineering Laboratory of the Dominion Physical Laboratory, New Zealand. The work of the laboratory includes mechanical testing, metallography, and research on manufacturing problems. —C. O.

Survey Finds : Chrome Plating Well Suited to Piston Rings. H. O. Mathews. (S.A.E. Journal, 1947, vol. 55, Oct., pp. 33–35). Some of the results of a survey of the experience of American piston-ring manufacturers and bus-fleet operators with the use of chromium-plated piston rings and cylinders are reported. Chromium-plated cylinder walls are considered to be not entirely satisfactory, and chomium-plated rings and

walls are found not to work well together. Chromium-plated rings, however, are thought to reduce wear rates and to be very suitable for heavy-duty operation.—C. O.

Cylinder Wear in Diesels—What Causes It and How It Can Be Measured. (S.A.E. Journal, 1947, vol. 55, Oct., pp. 31–32, 43). A composite digest is made of five papers, on wear in diesel engines, presented at the Summer Meeting of the Society of Automotive Engineers in June, 1947, by B. M. Berry, A. J. Blackwood, L. A. Blanc, K. H. Effman, and N. C. Penfold. The parts played in wear by corrosion caused by sulphur in the fuel, by abrasion, and by scuffing are considered and the techniques of measuring wear are briefly indicated. —C. O.

The Selection and Evaluation of Aircraft Metals. R. A. Slipper. (Australian Institute of Metals : Australasian Engineer, 1947, Sept. 8, pp. 65–75). A summary is made of the physical and mechanical properties and fabrication characteristics of the metals and alloys used in the construction of radial aircraft engines, and trainer and fighter airframes.—C. O.

Metallurgical and Structural Investigation of Steel Castings for Aircraft. L. W. Smith and L. D. Morris. (Transactions of American Society for Metals, 1947, vol. 38, pp. 848–874). An account is given of a comparison of the chemical and physical properties and the structure of statically and centrifugally cast steel aircraft components, and of identical components made by forging. From the results of the tests it is concluded that castings may be obtained which are sound enough and with sufficiently good properties to supplement or replace present types of fabricated components in the main structures of aeroplanes.—C. O.

The Breadths of X-Ray Diffraction Lines from Martensite. J. A. Wheeler and M. A. Jaswon. (Journal of The Iron and Steel Institute, 1947, vol. 157, Oct., pp. 161–172). The variation with Bragg angle of the breadths of X-ray diffraction lines from martensite has been investigated experimentally, using the Jones method of correction for instrumental broadening. The results indicate that the line broadening of martensite is due to balanced internal stresses rather than small particles.

X-Ray Study of Defects in Metallurgical Products. J. M. Vialle. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, Sept., pp. 349–379). Methods of detecting defects with X-rays are reviewed. Reference is made to photo-electric detection, fluoroscopy, radiography, stereo-radiography, " tomography," (the selective examination of internal layers), and the use of gamma rays. The industrial applications of radiography for the examination of castings and welded joints are also considered. —J. C. R.

X-Ray Examination of Butt Welds. W. D. Garrick. (British Association : Engineering, 1947, vol. 164, Oct. 24, pp. 405–407). The setting up of X-ray equipment for the examination of welds in pressure vessels is described and factors affecting definition, exposure time, use of salt or metal intensifying screens, and selection of tube voltage are considered. Examples of the interpretation of radiographs are illustrated and discussed.—R. A. R.

The Strength of Welded Joints at Low Temperatures and the Selection and Treatment of Steels Suitable for Welded Structures. O. Graf. (Welding Journal, 1947, vol. 27, Sept., pp. 508-s–517-s). A series of tests on welded steel girders, carried out in order to determine the cause of brittle failure at low temperatures of such structures as bridges, is described. The following factors were found to be of significance : Chemical composition and methods of production of the steel, size of the welded components, shape of the structure, welding technique and conditions, residual stresses, temperature of the structure in service, and type and magnitude of loading. The groove-weld-bend or bead-bend test is suggested as a means of determining the suitability of a steel for welded structures exposed to low temperatures.—C. O.

Metallurgical Examination of Japanese Homare-II Aircraft Engine No. 11515. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1468 : H.M. Stationery Office).

Metallurgical Examination of Two Japanese Aircraft Bank and Turn Indicators. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1485 : H.M. Stationery Office).

METALLOGRAPHY

Limits of Resolution of the Visual Microscope. N.-G. Neuweiler. (Microtecnic, 1947, vol. 1, June, pp. 143–151). Methods of determining the limit of resolution of a microscope are explained and means of increasing the resolving power are discussed.—R. A. R.

The Electron Microscope. J. Hillier. (Industrial Radiography, 1947, vol. 6, Summer Issue, pp. 25–31). A short comparison is made between the electron microscope and the light microscope. Mention is made of techniques which have been developed for producing replicas of surfaces ; these should prove of great value to the metallurgist.—C. O.

Behaviour of a Chromium Steel in the Jominy Hardenability Test. W. J. Pumphrey. (Journal of The Iron and Steel Institute, 1947, vol. 157, Sept., pp. 27–30). A metallurgical examination, including examination by the electron microscope, has been made of the structures developed along the length of a Jominy bar of a steel possessing unusual hardenability characteristics at certain slow rates of cooling. It has been shown that the structures can be explained on the basis of a derived S-curve which is not abnormal in type.

Factors Influencing the Pearlitic Microstructure of Annealed Hypoeutectoid Steel. R. A. Grange. (Transactions of American Society for Metals, 1946, vol. 38, pp. 879–908). *See* Journ. I. and S.I., 1946, No. II, p. 140A.

A Periodic Chart for Metallurgists. C. A. Zappfe. (Transactions of American Society for Metals, 1946, vol. 38, pp. 239–270). *See* Journ. I. and S.I., 1946, No. II, p. 139A.

The Chromium-Oxygen Equilibrium in Liquid Iron. Hsin-Min Chen and J. Chapman. (Transactions of American Society for Metals, 1947, vol. 38, pp. 70–116). *See* Journ. I. and S.I., 1946, No. II, p. 140A.

Experimental Studies of Continuous Cooling Transformations. C. A. Liedholm. (Transactions of American Society for Metals, 1946, vol. 38, pp. 180–208). *See* Journ. I. and S.I., 1946, No. II, p. 140A.

Changes in Austenitic Chromium–Nickel Steels during Exposures at 1100° to 1700° F. P. Payson and C. H. Savage. (Transactions of American Society for Metals, 1947, vol. 39, pp. 404–452). *See* Journ. I. and S. I., 1946, No. II, p. 140A.

Transformations in Krupp Type Carburising Steels. A. R. Troiano and J. E. De Moss. (Transactions of American Society for Metals, 1947, vol. 39, pp. 788–800). *See* Journ. I. and S.I., 1946, No. II, p. 141A.

Stability of Austenite in Stainless Steels. C. B. Post and W. S. Eberly. (Transactions of American Society for Metals, 1947, vol. 39, pp. 868–890). *See* Journ I. and S.I., 1946, No. II, p. 140A.

Isothermal Transformation of Austenite. A. Hultgren. (Transactions of American Society for Metals, 1947, vol. 39, pp. 915–1005). *See* Journ. I. and S.I., 1946, No. II, p. 141A).

A Metallographic Etchant to Reveal Temper Brittleness in Steel. J. B. Cohen, A. Hurlich, and M. Jacobson. (Transactions of American Society of Metals, 1947, vol. 39, pp. 109–138. (*See* Journ. I. and S. I., 1946, No. II, p. 139A).

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The Deformation of Metals and Alloys. J. Ternisien. (Métallurgie, 1947, vol. 79, Apr., pp. 7–10). An examination of the deformation of metals and alloys by X-ray methods is described under the following headings: Reticular distortion; grain orientation; and modifications of the crystal structure.—J. C. R.

The Metallographic Constituents of Steels and Cast Iron as Affecting Flame Hardening. O. M. Harrelson. (Welding Journal, 1947, vol. 27, Sept., pp. 771–775). The microstructures of the constituents of steel and cast iron are illustrated, and the stationary, progressive, spinning, and combination methods of flame-hardening are briefly described.—C. O.

Effect of Heat Treating and Cold Rolling on Crystal Structure of Austenitic Manganese Steel. N. P. Goss. (Steel, 1947, vol. 121, Sept. 29, pp. 74–75, 117–120; Oct. 6, pp. 98–100, 132–144). The application of X-ray diffraction methods to the examination of the crystal structure of Hadfield-type austenitic manganese steels is described in detail. The mosaic theory of structure is used to explain the changes in the diffraction patterns given by steel strip after various heat-treatments and degrees of cold rolling.—C. O.

Peculiarities of Primary Crystallization in Thick Centrifugally Cast Steel Tubes: Major Segregations, Internal Stresses. J. Cailland. (Bulletin du Cercle d'Études des Métaux, 1947, vol. 4, Mar., pp. 421–460). In the first part of this article the author describes the peculiar characteristics of segregation during solidification and of primary crystallization, with particular reference to the formation of dendrites and macro- and microspheroids. In the second part he deals with internal stress in thick centrifugally cast steel tubes and their measurement. Results of tests carried out after different heat-treatments are presented.—J. C. R.

Metallurgical Examination of German Centrifugally Cast Gun Barrels Ex Bochumer Verein Plant. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1461 : H.M. Stationery Office).

Comparison of Austenitic Grain-Growth Tendencies of Steel in the As-Cast and As-Forged Conditions. P. Bastien. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 20–26). The author, using the cementation method of MacQuaid and Ehn, compares the austenitic grain-growth tendencies of two basic open-hearth steels, killed by different additions of aluminium, in the as-cast and as-forged conditions. Although, in each case, the initial grain-size of the austenite is nearly the same ; appreciable differences are found in the rate of growth over a range of temperature ; the temperature at which the grain begins to grow is lower in the case of the forged steel than the cast steel, but the rate of grain growth is far more rapid in the cast steel than in the forged steel. The results obtained are illustrated by micrographs and grain-growth curves.—R. F. F.

Contribution to the Study of Steels with Intermediate Structures Obtained by Low-Temperature Tempering. G. Délbart and R. Potaszkin. (Revue de Métallurgie, 1946, vol. 43, Mar.–Apr., pp. 84–95). A series of 38 micrographs shows the effect of tempering temperature with or without subsequent annealing upon the formation and disappearance of bainite in a chromium–molybdenum steel (0·3% C, 2% Cr, 0·5% Mo). The physical properties cannot be correlated exactly with the microstructure, but at tempering temperatures between 200° and 550° C with water-quenching, apart from a critical region at close to 300° C., the physical properties compare favourably with those obtained by oil-quenching and subsequent annealing. Low temperature heat-treatment should be worth further investigation, as it should give similar results with other steels if the exact temperature conditions are known. —R. A. H.

On the Relation between Deformation and Recrystallization Texture of Nickel–Iron with Cubic Orientation. J. F. H. Custers. (N. V. Philips' Gloeilampenfabrieken, Reprint No. 1727 : Physica, 1947, vol. 13, pp. 97–116). The object of the investigation described was to discover the origin of the crystal grains in cubic orientation in a 50/50 nickel–iron alloy after cold-rolling. The results provided confirmation of Burgers' theory of recrystallization, but they also showed that modification of the theory in some respects is desirable.—R. A. R.

Study on the Recrystallisation of a Special Nickel-Chromium Austenite. A. Portevin and R. Castro. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 270–274). Recrystallization, superheating, and annealing curves were traced for an austenite (25% Ni, 12% Cr, and 2% Mn), by the determination of grain-size, hardness due to cold-drawing (5% to 100% extension), and annealing at temperatures of 750° to 1100° and 1200° C. Apart from some irregularities in the superheated region, these curves resemble those of metals without transformation points.—R. F. F.

Study of a High-Speed Steel Ingot. C. F. Sawyer, jun. (Iron Age, 1947, vol. 160, Oct. 16, pp. 140–142). Data obtained in an investigation into alloy segregation in a normal production ingot of 18/4/1 tungsten–chromium–vanadium high-speed steel are presented.—C. O.

Overheating of Carbon Steels. L. Colombier. (Bulletin du Cercle d'Études des Métaux, 1942, vol. 3, Dec., pp. 265–268). Details are given of micrographic examinations of the structure of 1% carbon steels after overheating at 940° and 1050° C.—J. C. R.

Anomalies of Supercooling. G. Coingt. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, June, pp. 325–340 ; Sept., pp. 380–382). An account is given of tests carried out on two steels, using different-sized test-pieces, to study the variation in the quantity of residual austenite as related to the speed of cooling. The test-pieces were quenched in various media from different temperatures and their hardness measured before annealing and after annealing at 400°, 500°, and 600° C. The results are tabulated and also presented graphically.—J. C. R.

Oxygen in Rimming Steel. I. Musatti and G. Ziliani. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 225–243). The liquation of oxygen in rimming steel was studied using special methods of taking samples and an apparatus giving very accurate results. The experiments lead to the conclusion that oxygen is one of the elements least subject to liquation. Even with relatively low amounts of oxygen, local concentrations high enough to produce hot-brittleness can be obtained. Ingots cast from the same melt show similar concentrations of oxygen, and these can still be observed after the steel has been hot-rolled. The examination of equilibria which are established during the solidification of the steel (carried out on blooms) shows conditions, which on the whole, are in agreement with those described by Hultgren and Phragmen. The size and distribution of inclusions are regulated by the same phenomena which determine the variations of the direction of curves relating the product of the percentages of carbon and oxygen to the distance from the rim.—R. F. F.

Morphology of Micrographic Structures. A. Portevin. (Revue de Métallurgie, 1944, vol. 41, Oct., pp. 313–330). The mechanism of crystallization of metals and alloys is discussed when : (1) The mass of the metal is amorphous ; (2) the mass is crystalline and crystallization is proceeding ; (3) the mass is crystalline and undergoing transformation or decomposition.—R. F. F.

The Formation and Development of Sub-Microscopic Nuclei in Allotropic Transformations. P. Laurent. (Revue de Métallurgie, 1945, vol. 42, Jan., pp. 22–26). The mechanism of the formation and growth of nuclei is discussed from the mathematical standpoint.—R. F. F.

CORROSION

The Application of Electrochemical Theory to Corrosion. G. M. Willis. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy : Australasian Engineer, 1947, Oct. 7, pp. 80–95). The electrochemical theory of corrosion is explained and the more recent literature on corrosion investigations is reviewed.—R. A. R.

New Aspects of the Destruction of Metals by Local Cells. K. Wickert. (Korrosion und Metallschutz : Archiv für Metallkunde, 1947, vol. 1, June, pp. 251–259). The theory of the corrosion of iron by local cells is discussed and experiments are described in which two electrodes, both of 0·05% carbon steel, were immersed in separate flasks containing $N/10$ NaCl solution ; one was subjected to a stream of oxygen and the other to nitrogen. The electrodes were conected externally through an ammeter. This constituted an oxygen concentration cell with an extremely low oxygen content in the anode electrolyte ; the cell was referred to as the N_2-O_2 chain. Loss-in-weight determinations were made under various test conditions which included treatment of the electrodes by filing, grinding, and polishing. The following laws governing the electrochemical disappearance of the metal were established : (1) In the N_2-O_2 chain with active electrodes in an indifferent electrolyte the cathode suffers the greater loss of metal, whilst with passive electrodes the anode suffers the

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Radiography of Metals and Alloys. P. Skulari. (Hutnické Listy, 1947, vol. 1, No. 11, Supplement). [In Czech]. Detailed descriptions are given of the Laue, Bragg, Debye-Scherrer, and other methods of studying metals with X-rays, and the advantages and disadvantages of each are discussed.

X-Ray Crystallography and Its Application to Metallurgy. P. Bastien. (Chimie et Industrie, 1941, vol. 45, June, pp. 531–540). The apparatus and methods used in X-ray crystallography are reviewed and its application to metallurgy is discussed.—R. F. F.

The Deformation of Metals and Alloys. J. Ternisien. (Métallurgie, 1947, vol. 79, Apr., pp. 7–10). An examination of the deformation of metals and alloys by X-ray methods is described under the following headings: Reticular distortion; grain orientation; and modifications of the crystal structure.—J. C. R.

The Metallographic Constituents of Steels and Cast Iron as Affecting Flame Hardening. O. M. Harrelson. (Welding Journal, 1947, vol. 27, Sept., pp. 771–775). The microstructures of the constituents of steel and cast iron are illustrated, and the stationary, progressive, spinning, and combination methods of flame-hardening are briefly described.—C. O.

Effect of Heat Treating and Cold Rolling on Crystal Structure of Austenitic Manganese Steel. N. P. Goss. (Steel, 1947, vol. 121, Sept. 29, pp. 74–75, 117–120; Oct. 6, pp. 98–100, 132–144). The application of X-ray diffraction methods to the examination of the crystal structure of Hadfield-type austenitic manganese steels is described in detail. The mosaic theory of structure is used to explain the changes in the diffraction patterns given by steel strip after various heat-treatments and degrees of cold rolling.—C. O.

Peculiarities of Primary Crystallization in Thick Centrifugally Cast Steel Tubes: Major Segregations, Internal Stresses. J. Cailland. (Bulletin du Cercle d'Études des Métaux, 1947, vol. 4, Mar., pp. 421–460). In the first part of this article the author describes the peculiar characteristics of segregation during solidification and of primary crystallization, with particular reference to the formation of dendrites and macro- and microspheroids. In the second part he deals with internal stress in thick centrifugally cast steel tubes and their measurement. Results of tests carried out after different heat-treatments are presented.—J. C. R.

Metallurgical Examination of German Centrifugally Cast Gun Barrels Ex Bochumer Verein Plant. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1461 : H.M. Stationery Office).

Comparison of Austenitic Grain-Growth Tendencies of Steel in the As-Cast and As-Forged Conditions. P. Bastien. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 20–26). The author, using the cementation method of MacQuaid and Ehn, compares the austenitic grain-growth tendencies of two basic open-hearth steels, killed by different additions of aluminium, in the as-cast and as-forged conditions. Although, in each case, the initial grain-size of the austenite is nearly the same ; appreciable differences are found in the rate of growth over a range of temperature ; the temperature at which the grain begins to grow is lower in the case of the forged steel than the cast steel, but the rate of grain growth is far more rapid in the cast steel than in the forged steel. The results obtained are illustrated by micrographs and grain-growth curves.—R. F. F.

Contribution to the Study of Steels with Intermediate Structures Obtained by Low-Temperature Tempering. G. Délbart and R. Potaszkin. (Revue de Métallurgie, 1946, vol. 43, Mar.–Apr., pp. 84–95). A series of 38 micrographs shows the effect of tempering temperature with or without subsequent annealing upon the formation and disappearance of bainite in a chromium–molybdenum steel (0·3% C, 2% Cr, 0·5% Mo). The physical properties cannot be correlated exactly with the microstructure, but at tempering temperatures between 200° and 550° C with water-quenching, apart from a critical region at close to 300° C., the physical properties compare favourably with those obtained by oil-quenching and subsequent annealing. Low temperature heat-treatment should be worth further investigation, as it should give similar results with other steels if the exact temperature conditions are known.—R. A. H.

On the Relation between Deformation and Recrystallization Texture of Nickel–Iron with Cubic Orientation. J. F. H. Custers. (N. V. Philips' Gloeilampenfabrieken, Reprint No. 1727 : Physica, 1947, vol. 13, pp. 97–116). The object of the investigation described was to discover the origin of the crystal grains in cubic orientation in a 50/50 nickel–iron alloy after cold-rolling. The results provided confirmation of Burgers' theory of recrystallization, but they also showed that modification of the theory in some respects is desirable.—R. A. R.

Study on the Recrystallisation of a Special Nickel-Chromium Austenite. A. Portevin and R. Castro. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 270–274). Recrystallization, superheating, and annealing curves were traced for an austenite (25% Ni, 12% Cr, and 2% Mn), by the determination of grain-size, hardness due to cold-drawing (5% to 100% extension), and annealing at temperatures of 750° to 1100° and 1200° C. Apart from some irregularities in the superheated region, these curves resemble those of metals without transformation points.—R. F. F.

Study of a High-Speed Steel Ingot. C. F. Sawyer, jun. (Iron Age, 1947, vol. 160, Oct. 16, pp. 140–142). Data obtained in an investigation into alloy segregation in a normal production ingot of 18/4/1 tungsten–chromium–vanadium high-speed steel are presented.—C. O.

Overheating of Carbon Steels. L. Colombier. (Bulletin du Cercle d'Études des Métaux, 1942, vol. 3, Dec., pp. 265–268). Details are given of micrographic examinations of the structure of 1% carbon steels after overheating at 940° and 1050° C.—J. C. R.

Anomalies of Supercooling. G. Coingt. (Bulletin du Cercle d'Études des Métaux, 1946, vol. 4, June, pp. 325–340 ; Sept., pp. 380–382). An account is given of tests carried out on two steels, using different-sized test-pieces, to study the variation in the quantity of residual austenite as related to the speed of cooling. The test-pieces were quenched in various media from different temperatures and their hardness measured before annealing and after annealing at 400°, 500°, and 600° C. The results are tabulated and also presented graphically.—J. C. R.

Oxygen in Rimming Steel. I. Musatti and G. Ziliani. (Chimie et Industrie, 1941, vol. 45, Mar., Special Issue, pp. 225–243). The liquation of oxygen in rimming steel was studied using special methods of taking samples and an apparatus giving very accurate results. The experiments lead to the conclusion that oxygen is one of the elements least subject to liquation. Even with relatively low amounts of oxygen, local concentrations high enough to produce hot-brittleness can be obtained. Ingots cast from the same melt show similar concentrations of oxygen, and these can still be observed after the steel has been hot-rolled. The examination of equilibria which are established during the solidification of the steel (carried out on blooms) shows conditions, which on the whole, are in agreement with those described by Hultgren and Phragmen. The size and distribution of inclusions are regulated by the same phenomena which determine the variations of the direction of curves relating the product of the percentages of carbon and oxygen to the distance from the rim.—R. F. F.

Morphology of Micrographic Structures. A. Portevin. (Revue de Métallurgie, 1944, vol. 41, Oct., pp. 313–330). The mechanism of crystallization of metals and alloys is discussed when : (1) The mass of the metal is amorphous ; (2) the mass is crystalline and crystallization is proceeding ; (3) the mass is crystalline and undergoing transformation or decomposition.—R. F. F.

The Formation and Development of Sub-Microscopic Nuclei in Allotropic Transformations. P. Laurent. (Revue de Métallurgie, 1945, vol. 42, Jan., pp. 22–26). The mechanism of the formation and growth of nuclei is discussed from the mathematical standpoint.—R. F. F.

CORROSION

The Application of Electrochemical Theory to Corrosion. G. M. Willis. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy : Australasian Engineer, 1947, Oct. 7, pp. 80–95). The electrochemical theory of corrosion is explained and the more recent literature on corrosion investigations is reviewed.—R. A. R.

New Aspects of the Destruction of Metals by Local Cells. K. Wickert. (Korrosion und Metallschutz : Archiv für Metallkunde, 1947, vol. 1, June, pp. 251–259). The theory of the corrosion of iron by local cells is discussed and experiments are described in which two electrodes, both of 0·05% carbon steel, were immersed in separate flasks containing *N*/10 NaCl solution ; one was subjected to a stream of oxygen and the other to nitrogen. The electrodes were conected externally through an ammeter. This constituted an oxygen concentration cell with an extremely low oxygen content in the anode electrolyte ; the cell was referred to as the N_2-O_2 chain. Loss-in-weight determinations were made under various test conditions which included treatment of the electrodes by filing, grinding, and polishing. The following laws governing the electrochemical disappearance of the metal were established : (1) In the N_2-O_2 chain with active electrodes in an indifferent electrolyte the cathode suffers the greater loss of metal, whilst with passive electrodes the anode suffers the

greater loss ; (2) in the N_2-O_2 chain with active electrodes in an indifferent electrolyte the cathode metal loss is greater than the anode metal loss, calculated from the flow of electrons, by a magnitude of more than the first order ; and (3) with single electrodes the metal loss during treatment with oxygen in an indifferent electrolyte is, for active surfaces, the same as the cathode metal loss in the N_2-O_2 chain for active surfaces, and similarly for passive surfaces. Under treatment with nitrogen the single-electrode metal loss is less than that of anode metal loss in the N_2-O_2 chain.—R. A. R.

Corrosion. J. C. Hudson. (Congrès International de Corrosion : Iron and Steel, 1947, vol. 20, Nov., pp. 507–518). An outline is given of the organization and functions of the various sub-committees of the Corrosion Committee of the British Iron and Steel Research Association, and a survey is made of the work in progress. A list of papers and Special Reports published by The Iron and Steel Institute on the subject of corrosion is appended.—J. R.

Metal Loss and Catalysis. K. Wickert. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 270–275). It is shown that in the corrosion of metals in NaCl solution the NaCl acts as an accelerator to the "electron-taking" reaction of the oxygen. Experiments in the study of this accelerating action are described.—R. A. R.

The Protection of Iron Parts in Contact with Sea Water by Galvanic Contact with Zinc. F. Tödt. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 288–289). Earlier tests have shown that iron cooler tubes can be protected from corrosion by dilute salt solutions if placed in contact with zinc in the proportion of 14 sq. cm. of zinc surface to every 120 sq. cm. of iron surface. As such a high proportion of zinc is not practicable, the author carried out additional tests using synthetic sea water produced by Wassermann's method. The surprising result was that when the proportion of zinc surface to iron surface was only 1 to 1000 the iron was fully protected against corrosion.—R. A. R.

The Relationship of the Atmospheric Corrosion of Metals to Sulphur-Bearing Impurities in the Air. G. Schikorr. (Metalloberfläche, 1947, vol. 1, May, pp. 115–116).

The Inhibiting Effect of Nicotinic Acid (β-pyridine-carboxylic acid) on Metals. L. Hertelendi. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 275–278). Experiments are described in which the solubility of aluminium, zinc, and iron in acids containing different additions of nicotinic acid was studied.—R. A. R.

The Effect of Inhibitors and Inorganic Materials on the Corrosion of Iron in Hot Water. W. Machu. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 267–270). The effect of inhibitors and oxidizing agents on the solubility of iron in water at 60° C. was investigated. In neutral water the effect of inhibitors is to increase the solubility of iron and it requires the presence of an acid to make the inhibiting action effective. The passivating effect of potassium bichromate is reduced by additions of waterglass or hay extract, although these by themselves are good inhibitors. A dilute solution of potassium bichromate and waterglass is used for preventing corrosion in hot-water systems.—R. A. R.

The Behaviour of Metallic Materials in Relation to Very Dilute Aqueous Solutions. L. W. Haase. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 259–264). The effect on the progress of corrosion of changes in the composition of the attacking medium due to the initial reactions is discussed.—R. A. R.

Intergranular Corrosion of Cast Austenitic Stainless Steels. H. A. Pray. (Société Française de Métallurgie : Revue de Métallurgie : Iron and Coal Trades Review, 1947, vol. 155, Dec. 5, pp. 1106–1108). The sensitivity to intergranular corrosion of austenitic stainless steels was studied by loss-in-weight tests in boiling 65% nitric acid. Increasing the chromium content from 19% to 21% reduced the attack to practically zero, whilst increasing the nickel from 7% to 12%, or the nitrogen from 0·04% to 0·20% markedly increased the sensitivity to attack. In the cast form the amount of ferrite necessary to reduce or prevent susceptibility is not detrimental to the physical properties ; the presence of ferrite is, however, detrimental to the forging and rolling properties.—R. A. R.

New Photomicrographic Studies of the High-Temperature Oxidation of Iron. J. Dénard and O. Coquelle. (Revue de Métallurgie, 1946, vol. 43, Mar.–Apr., pp. 113–124). Specimens of Armco iron were oxidized in air for a standard period of 5 hr. in the temperature range from 600° to 1100° C. Loose coatings, or adherent coatings together with the base, were then set in Wood's metal, polished, and examined after etching with very dilute hydrochloric acid. The results show that up to 910° C. the FeO concentration increases with increasing temperature at the expense of the Fe_3O_4 concentration, whilst from 910° C. onwards, Fe_2O_3 begins to be formed and the Fe_3O_4 increased sharply, both at the expense of the FeO. Oxidation at constant temperature was found to proceed differently for the three oxides ; the FeO was formed according to an exponential law, whilst the Fe_3O_4 and the Fe_2O_3 developed linearly with time, the overall increase in thickness of the oxide coating being exponential, in agreement with results obtained by other methods.

The kinetics of the oxidation of iron are held to apply also to other metals where more than one oxide can be formed, and, in general, to all gas–solid reactions giving a solid reaction product.—R. A. H.

Scale (Iron Oxide). W. Trinks. (Industrial Heating, 1947, vol. 14, Oct., pp. 1601–1604). The causes of scale formation and the nature and properties of scale are considered.—R. A. R.

The Effect of the Oxide Coating on the Rate of Corrosion, Especially of Iron. F. Tödt. (Archiv für Metallkunde, 1947, vol. 1, June, pp. 249–251). The oxide coating on a metal has a most important effect on the rate of corrosion. The coating thickness varies between molecular dimensions and 1 mm. The electrochemical activity depends on the extremely thin layers. The formation and disappearance of the oxide skin on iron during solution of traces of iron in the first few seconds can be followed by photo-electric methods. Such tests have shown that the skin can be destroyed in a few seconds, whilst its development to full activity may take up to 1 hr. The rate of solution of iron in the first second (or even less time) was found to be at least ten times that in the subsequent period. The relation between the corrosion of iron in concentrated solutions and biochemical effects is discussed.—R. A. R.

Cathodic Corrosion Protection of Steel Studied at Dow Chemical's Metals Protection Laboratory. (Steel, 1947, vol. 121, Nov. 10, pp. 106–107, 124). A short summary is made of the results of investigations by the staff of the Dow Chemical Company of the efficiency of magnesium anodes in protecting underground steel structures, water storage tanks, ships, and domestic water-heaters against corrosion.—C. O.

The Cavitation Research Plant and the Stand for Cavitation Specimens. R. Meyer and F. Gerber. (Von Roll Mitteilungen, 1947, vol. 6, Dec., pp. 109–110). Brief descriptions are given of the special equipment developed by the L. von Roll A.G. for testing the cavitation resistance of metals.—R. A. R.

Caustic Cracking of Welded Steel Plate. H. M. Wilten. (Metal Progress, 1947, vol. 52, Nov., pp. 803–805). A failure resulting from caustic cracking in a welded steel reboiler at an oil refinery is described and illustrated. The reboiler consisted of a firebox-quality steel shell (A.S.T.M. specification *A*70) with forged steel flanges (A.S.T.M. specification *A*181), which, when in use, contained light hydrocarbons at a temperature of 358° F., and 100 lb./sq. in. gauge pressure.—C. O.

The Corrosion of Coke Cars. W. W. Stevenson. (Year-Book of the Coke-Oven Managers' Association, 1947, pp. 227–240). After a review of atmospheric and spray methods of testing the corrosion-resistance of steels, the results of tests on plates of ingot iron, mild steel, Scottish iron, copper-bearing steel, copper–chromium steel and Corten steel used in constructing coke cars are presented. Full-scale tests led to coke cars being constructed of Corten steel.—R. A. R.

INDUSTRIAL USES AND APPLICATIONS

Materials for Crushing, Grinding and Screening Machines. E. C. Blanc. (Echo des Mines, 1946, Sept., pp. 138–139). The use of French special steels in the manufacture of crushing, grinding, and screening machines is discussed.—R. F. F.

Utilization and Maintenance of Wire Rope. L. Sanderson. (Canadian Mining Journal, 1947, vol. 58, Jan., pp. 26–28; Apr. pp. 250–252). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 142).

Engineering Applications of Electrodeposited Coatings. M. B. Diggin. (Metal Finishing, 1947, vol. 45, June, pp. 78–80). A summary is made of the industrial uses of electrodeposited coatings of chromium, nickel, iron, copper, tin, and precious metals.—C. O.

Application Tables to Guide in the Selection of Materials. I. Z. Fox. (Product Engineering, 1947, vol. 18, Nov., pp. 165–169). A series of tables has been prepared giving, in a concise form suitable for the machine designer, the applications and chief characteristics of a wide variety of metals and alloys. Part I contains wrought carbon steels, wrought stainless steels, wrought alloy steels, and copper, nickel, and aluminium alloys.—R. A. R.

The Use of Heat Resisting Steels in the Manufacture of Gas Turbine Blades in Germany. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 1148 : H.M. Stationery Office).

An Alternative Form of Pressure Vessel of Novel Laminar Construction. H. Birchall and G. F. Lake. (Proceedings of the Institution of Mechanical Engineers, 1947, vol. 156, No. 3, pp. 349–358). The design, construction, and testing of pressure vessels built up by wrapping and welding steel plate around a central welded tube are discussed. This method will permit the manufacture of vessels far larger than can be produced as single forgings, using only such equipment as is found in a good engineering construction shop. Two laminar vessels have been in service at pressures up to 350 atm. for several years.—C. O.

Recent Developments in Metals and Their Processing. W. F. Craig, jun., R. A. Lubker, and W. E. Mahin. (Machine Design, 1947, vol. 19, Oct., pp. 71–78). In this review of metallurgical developments in recent years, mention is made of the following items: The "H"-band steel specifications; boron-treated steels; very low-carbon stainless steels; tool steels containing up to 2% of carbon and 5% of vanadium; thermo-setting plastic resins as core binders; the design of castings; centrifugal, die, permanent-mould, and precision castings; the vacuum-casting process; helium-arc welding, brazing, and powder metallurgy.—C. O.

The Economic Importance of High Quality Steels. F. Brühl. (Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 384–358). Examples are cited of the savings in power consumption and material achieved by applying alloy steels in steam and electric power stations, coal mines, machine shops, and heat-treatment plants, and the efficiency of the electric furnace for producing them is considered. A production schedule for alloy steels for different purposes in the framework of the permitted annual production of 10·7 million tons of steel ingots is proposed.—R. A. R.

Armour of Japanese Airplanes. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./894 : H.M. Stationery Office).

Metallurgical Examination of Four Different Types of Japanese Aircraft Spark Plugs. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1488 : H.M. Stationery Office). The alloys used included high-alloy nickel-chromium steels.—M. A. V.

HISTORICAL

John Cockerill and His Work. L. A. Berland. (Revue Universelle des Mines, 1947, Series 9, vol. 3, No. 11, pp. 529–537). The story of the life of John Cockerill, and the history of the works he founded, from their creation to the present day are told.—R. F. F.

Spencer Wire Company—Oldest Living Wire Mill in America. K. B. Lewis. (Wire and Wire Products, 1947, vol. 22, Sept., pp. 651–656, 695). A detailed account is given of the history of the Spencer Wire Company, Worcester, Mass.—C. O.

Is the Prehistoric Ring Found at Bytčí Skála of Cast Iron ? F. Píšek. (Hutnické Listy, 1947, vol. 2, No. 1, pp. 9–10). [In Czech.] This letter is a request in the name of Czechoslovakian and other metallurgists and foundrymen to have the iron ring, found in a cave near Brno, examined by modern methods to determine whether it was cast or forged. (*See* Historical Note No. 3, Journ. I. and S.I., 1947, vol. 156, Aug., p. 476).—R. A. R.

BOOK NOTICES

JIMENO, E. "*El Problema de la Corrosion Metalica.*" (Ministerio de Marina, Instituto Español de Oceanografia) 8vo, pp. 237. Madrid, 1947.

The author sets out to present a concise and up-to-date account of the problem of metallic corrosion, based on the published work of the many investigators in this field. After a preliminary discourse on the industrial importance of corrosion, and the organization of research on its prevention, in Great Britain, America, and Germany, he reviews the basic theories of corrosion, electrical and chemical. The question of atmospheric corrosion is then dealt with at some length, in the light of these theories. A chapter on the corrosion of metals and alloys in general contains a table of representative metals and alloys and their resistances to various corroding agents. Corrosion

fatigue, intergranular corrosion, and effects of marine organisms are all considered, and the final chapter discusses the various methods of protecting metals against corrosion, and their specific applications. A selected chronological bibliography of books is appended, covering the period 1896–1947.—M. A. V.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Anhaltszahlen für die Wärmewirtschaft insbesondere auf Eisenhüttenwerken.*" Nach Zahlenunterlagen und Versuchsergebnissen, gesammelt vom Verein deutscher Eisenhüttenleute durch dessen Energie- und Betriebswirtschaftsstelle. Bearbeitet, ergänzt und herausgegeben von Kurt Rummel. 4. Auflage der "Anhaltszahlen für den Energieverbrauch in Eisenhüttenwerken." La. 8vo, pp. viii + 224. Illustrated. Düsseldorf, 1947: Verlag Stahleisen, m.b.H.

This book forms the 4th edition of "Anhaltszahlen für den Energieverbrauch in Eisenhüttenwerken" revised and brought up-to-date by Dr. Kurt Rummel. It deals with the study of the utilization of heat energy in coke-ovens, blast-furnaces, steel plants, foundries, forges and mills, annealing furnaces, gas producers and works power stations, and covers also the energy requirements of water supply and space-heating. There are 387 tables in the text, which provide information on, for example, the calorific values of fuels, the moisture contents and thermal properties of ores, the physical properties of refractories—all mainly of German origin—the working temperatures and thermal efficiencies of typical installations, the times for reheating, and the energy required for rolling given steel sections, the heat balance of cupolas and many similar applications of heat and electrical energy. The work is further illustrated with 223 line drawings, graphs, and Sankey diagrams: these last indicate in a very clear form the intake, losses and utilization of heat in a number of industrial processes. Tables of the British, American, and German equivalents of the units of measurement employed are also included.—J. P. S.

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Annual Statistical Report 1946.*" 8vo, pp. 162. New York: The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Report on Standard Samples for Spectrochemical Analysis.*" (Technical Publication No. 58-A). 8vo, pp. v + 23. Philadelphia, 1947: The Society. (Price 7*s.* 6*d.*).

BALLAY, M. and G HÉNON. "*Commission technique de la métallurgie des fontes. Les fontes spéciales.*" 8vo, pp. 34. Illustrated. Paris, 1947: Centre technique des Industries de la fonderie.

BARRINGER, E. C. "*The Story of Scrap.*" 8vo, pp. 152. Washington, D.C.: Institute of Scrap Iron and Steel. (Price $2.75).

BETHLEHEM STEEL CO. "*Properties of Frequently Used Carbon and Alloy Steels.*" (Booklet 211). Third Edition. 8vo, pp. 131. Illustrated. Bethlehem: The Company.

BOARD OF TRADE. Working Party Reports. "*Cutlery.*" 8vo, pp. 38. London, 1947: H.M. Stationery Office.

BRITISH IRON AND STEEL FEDERATION. "*Statistical Year Book for 1946. (Tariff Supplement).*" London: The Federation.

BRITISH IRON AND STEEL FEDERATION. COMMITTEE OF EUROPEAN ECONOMIC CO-OPERATION. "*Reports of Technical Committees on Iron and Steel, Hard Coke.*" (Supplement to Monthly Statistical Bulletin). 8vo, pp. 59. London, 1947: The Federation.

BUCHAN, S. "*Rubber to Metal Bonding.*" London: Crosby Lockwood and Co., Ltd. (Price 21*s.*).

CARD, H. S. "*Electric Resistance Welding Bibliography.*" 8vo, pp. 11. Cleveland, Ohio: The Author. (Price $2.00).

COLCLOUGH, T. P. "*Some Technical Aspects of the Reconstruction Programme.*" (The Cleveland Scientific and Technical Institution. Second Harold Wright Lecture). Nov. 12, 1947. 8vo, pp. 27. Middlesbrough.

COZZO, G. "*Le Origini della Metallurgia; i Metalli e Gli Dei.*" Pp. 343. Rome, 1945: G. Bardi.

FISCHER, JOHANN CONRAD. "*The Metallurgist Johann Conrad Fischer 1773–1854 and His Relations with Britain.*" La. 8vo, pp. 53. Illustrated. Schaffhausen, 1947: George Fischer, Ltd.

GARRIDO, J. and J. ORLAND. "*Los Rayos X y la Estructura Fina de los Cristales. Fundamentos Teoricos y Metodos Practicos.*" Prologo del Julio Palacios. 4to. pp. xiii + 260. Illustrated. Madrid, 1946: Dossal, S. A. (Price 148 pesetas).

IRON AND STEEL INSTITUTE. Bibliographical Series No. 5A. "*Bibliography on the Manufacture, Properties, and Testing of Steel Castings (Not including Moulding Sands).*" Covering the period from 1937 to 1946. (In continuation of Bibliography No. 5, covering the period 1920 to 1937). With an Appendix. "*Bibliography on the Centrifugal Casting of Steel.*" Covering the Period from 1920–1946. 8vo, pp. 72. London, 1947: The Institute. (Price: Non-Members, 2*s.* 6*d.*; Members, 1*s.*).

IRON AND STEEL INSTITUTE. Bibliographical Series No. 14. "*Bibliography on Steel Converter Practice (Including Multiplex Processes)*" (Covering the Period 1925 to 1946). 8vo, pp. 39. London, 1947: The Institute. (Price: Non-members 2*s.* 6*d.*; Members 1*s.* 3*d.*).

KIEFFER, R. and W. HOTOP. "*Métallurgie des Poudres.*" Traduit de l'allemand par P. Naslin. 8vo, pp. xvi + 392. Illustrated. Paris: Dunod (Price 1680 francs).

REE, R. C. van. "*Materialen voor Metalbewerkers.*" Pp. 169. Illustrated. Haarlem, 1947: A. Kemperman.

SILMAN, H. "*Chemical and Electroplated Finishes; The Protective Treatment of Metals.*" 8vo, pp. 432. London: Chapman and Hall, Ltd. (Price 30*s.* net).

SPOWERS, W. H. "*Hot Dip Galvanizing Practice.*" Second Edition. Pp. 200. Cleveland, Ohio: Penton Publishing Co. (Price $6.00).

STEPHANIDES, T. "*The Microscope and the Practical Principles of Observation.*" Pp. 160. London: Faber and Faber, Ltd. (Price 10*s.* 6*d.*).

UNION DES MÉTIERS SUISSES. "*Die Metallindustrie.*" Olten, 1946: Editions Hauenstein. (Price 4.40 Swiss francs).

VAN SOMEREN, E. H. S. "*Spectrochemical Abstracts.*" Vol. III. 1940–1945. 8vo, pp. 112. London: Adam Hilger, Ltd.

WEICHETT, W. "*Wege zur Hochstmechanisierung der Giesserei.*" Pp. 111. Illustrated. Düsseldorf und Possneck, 1945: Giesserei-Verlag. (Price 10.00 RM.)

WENGER, P. E. and R. DUCKERT. "*Traité de chimie analytique qualitative minérale.*" 8vo, pp. xii + 466. Geneva, 1946: Libraire de l'Université, Georg et Cie. (Price 43 Swiss francs).